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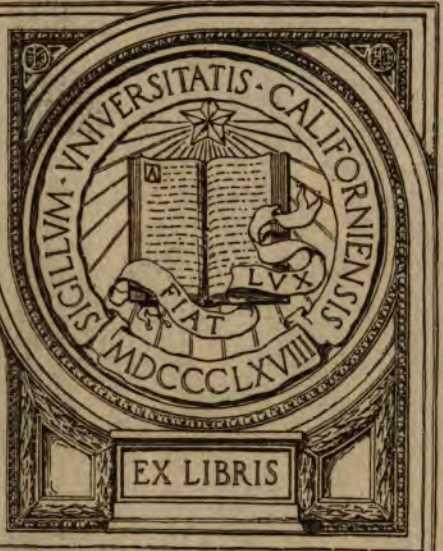

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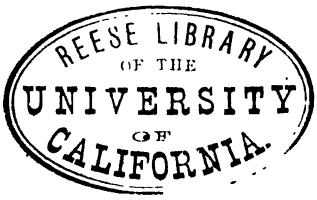
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THE

MATERIALS OF ENGINEERING.

IN THREE PARTS.

PART I.

NON-METALLIC MATERIALS:

STONE; TIMBER; FUELS; LUBRICANTS; ETC.

BY

ROBERT H. THURSTON, A.M., C.E.,

PROFESSOR OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY; PAST PRESIDENT AMERICAN SOCIETY OF MECHANICAL ENGINEERS; MEMBER OF AMERICAN SOCIETY CIVIL ENGINEERS; AMERICAN INSTITUTE MINING ENGINEERS; SOCIÉTÉ DES INGÉNIEURS CIVILS; VEREIN DEUTSCHER INGENIEURE; OESTERREICHISCHER INGENIEUR- UND ARCHITEKTEN VEREIN; INSTITUTION OF ENGINEERS AND SHIPBUILDERS OF SCOTLAND; BRITISH INSTITUTION OF NAVAL ARCHITECTS; FELLOW OF AM. ASSOC. FOR ADVANCEMENT OF SCIENCE; NEW YORK ACADEMY OF SCIENCES, ETC., ETC., ETC.

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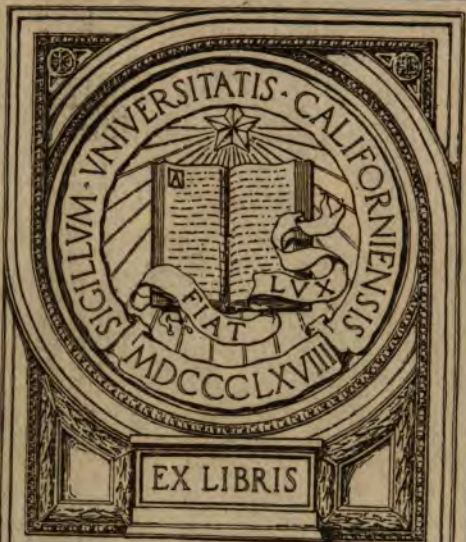

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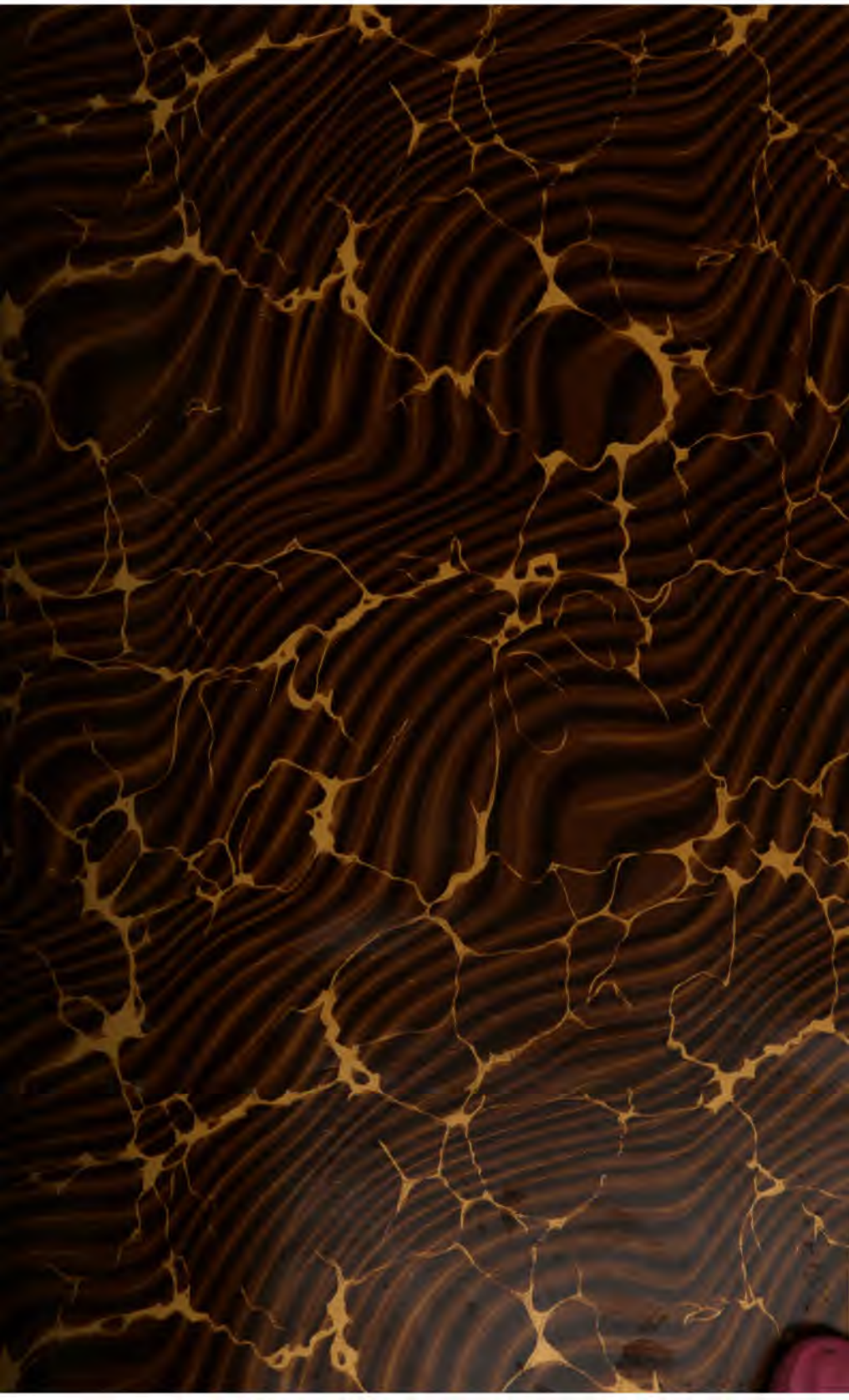

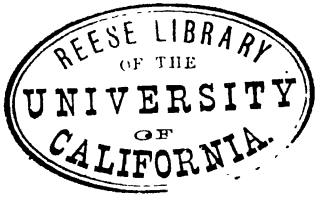
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FIG. 32.—THE GREAT CHESTNUT OF MOUNT ETNA.

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THE MATERIALS OF ENGINEERING.

PART I.

NON-METALLIC MATERIALS.

CHAPTER I.

STONES AND CEMENTS.

1. Use by the Mechanical Engineer.—The mechanical engineer makes comparatively little use of the materials of masonry. Their principal value to him is for use in foundations, and in structures protecting his machinery.

Of the stones, but few are well adapted to his purpose. Using them in foundations, he requires them to be strong and dense, hard and durable; and the mortars and cements used to bind them should be of the best possible quality. A foundation intended to bear the shock and tremor of moving machinery must, necessarily, be more carefully built, and must be constructed of more carefully selected materials than a foundation carrying a load at rest.

The civil engineer makes frequent use of all the materials of masonry.

There is given here a summary of the most important characteristics of these materials. For a more detailed account of them, reference may be made to special works on civil engineering. The mason uses for foundations natural stones which are either silicious, calcareous, or argillaceous in their character, and artifical stones, including the several varieties of brick. For special construction, he sometimes employs materials not in common use, as fire brick and fire clay. These materials are very rarely used in structures, to resist other than compressive stress.

2. Classification of Stones.—The system of Durocher and Bunsen classifies the stones by reference to their proportions of silica, and under a geological classification into igneous, metamorphic, sedimentary, and calcareous. The igneous or plutonic rocks were produced by original solidification from fusion or by later volcanic action. The metamorphic rocks are sedimentary, but have been altered by heat, pressure, chemical, and other agencies. The sedimentary rocks are the result of the abrasion of older rocks by water, and subsequent condensation and solidification under pressure. The calcareous rocks are composed of corals, as the "Coquina," or of the shells of marine animals which have usually, under the pressure of superincumbent rock and soil, become so compacted as to have lost their form, and to have united into dense and granular masses.

3. Silicious Stones.—The granitic group of igneous rocks is richest in silica, and its members are known as silicious stones. Of this class, granite, sienite, gneiss, greenstone, and trap, and the harder varieties of sandstone, are most commonly used.

4. Granite is a primary rock, and underlies the stratified rocks; it is, itself, unstratified. It is of a compact crystalline structure, and is composed of quartz, feldspar, and mica; its principal impurities are talc and hornblende. Its quartz is in the form of colorless or gray crystals; its feldspar is in opaque-white or flesh-colored crystals; and the mica appears as shining scales or grains.

Its quality varies considerably according to the proportions and mode of aggregation of its constituents. The greater the proportion of quartz, and the less the proportion of feldspar and mica, the greater the durability and hardness of the stone. Feldspar renders the stone lighter in color and easier to cut, and more susceptible to decomposition by solution of the potash contained in it; mica renders it friable; and hornblende heavy and tough.

The best kinds of granite are the most valuable of all our building stones, and it is extensively used for important works. Under exposure to fire it is, however, less durable

than many, in other respects, inferior stones. It is easy to quarry, and blocks may be obtained of any size. It is difficult to work, and therefore very costly to use if the stone must be dressed. Its specific gravity is about 2.66, and its weight 166 pounds per cubic foot, or nearly 2 tons per cubic yard (2659 kilogrammes per cubic metre).

Granite is found throughout all the Eastern States, in Canada, in many parts of the Alleghanies and Rocky Mountains, and usually wherever the later rock formations have been removed and left the underlying beds exposed. It is generally classified into gray and red.

Gray granite in immense quantities is found in Maine. That from Dix Island is very hard and strong. The granite of Hallowell has a greenish tint, and is very light-colored when first cut; it is fine-grained and durable, yet easily worked. Morgan's Bay granite is very strong, easily worked, and light-colored. Round Pond granite is fine-grained and polishes well. Gray granite of good quality is also found at Mt. Desert, Clark's and Fox Islands. In New Hampshire, the "Granite State," a fine granite is found at Pelham. Much of that found in this State is coarse, micaceous, and not very durable. In Vermont, the Barre granite is perhaps the best; it is light-colored and homogeneous. In Massachusetts, the Quincy granite has the greatest reputation. It has a dark bluish-gray color, is very durable, and takes a fine polish. In Rhode Island, at Westerly, is found granite of the very best quality; it is fine-grained, containing small particles of hornblende and black mica. It is much used for monumental purposes. In Connecticut, a very fine-grained granite is quarried at Mystic Bridge. That obtained at Millstone Point is rather dark in color, compact, with comparatively little hornblende or mica. In New Jersey, an excellent granite is found at Newfoundland.

Red granite of excellent quality is found along the Bay of Fundy. It is composed of red orthoclase, bluish quartz, and a little hornblende, with scarcely any mica. It is hard, and takes a fine polish. Similar granite is found on Forsyth's Island in the St. Lawrence. The Calais red granite comes

from near the St. Croix River in Maine. Very fine red granites are found at Lake Superior, and at many points in the Rocky Mountains. The Scotch Peterhead red granite is used considerably, but is not greatly superior to many of our native stones.

Talcose Granite, or Protogine, is one in which the mica is replaced by talc.

Sienite was first quarried at Siena or Syene in Egypt, whence its name. It is a granular rock closely resembling granite, and consists of feldspar and hornblende, with frequently quartz and mica. It is hard, tough, rather coarse-grained, and not susceptible of taking a polish. When the feldspar is not too readily decomposed by the removal of its potash when acted upon by the weather, it is the most durable of our granitic rocks, and affords an excellent material for rough and substantial work. Before making use of this stone, if it is obtained from a new quarry, its quality should be carefully tested.

5. **Gneiss and Mica Slate** are similar to granite in composition, are metamorphic rocks, and are found stratified. Granite, sienite, and gneiss resemble each other so closely that they are all frequently called granite by those who are not familiar with mineralogy.

Gneiss is less valuable than granite, as it cannot be obtained as readily in blocks of definite size, and as it does not as readily split in directions other than that of stratification. It is, however, a good building material, and, for the purposes of the engineer, answers frequently as well as granite.

Sienitic gneiss is a stratified sienite in which hornblende takes the place of mica.

A very slightly stratified gneiss is found at Concord, New Hampshire, and there are quarries of dark compact gneiss at Greenwich, Connecticut.

These stones are all much affected in quality by the presence of foreign elements. The oxides of iron are particularly injurious, causing discoloration and serious disintegration of the stone. Quarries of excellent granite, sienite, and gneiss

are found throughout the mountain ranges which extend along the coast of the United States.

6. Greenstone, Trap, and Basalt are plutonic unstratified rocks, consisting of hornblende and feldspar.* In the first named, the grains are not as coarse as in granite, and the others hardly exhibit the granular structure to the eye. The first two break up into blocks, and the latter into columns of prismatic form. They are found in veins and dykes, injected among stratified rocks of all ages. In color, they vary from nearly white, in some varieties of greenstone, to as nearly black in basalt, the difference of color being determined by variations in the proportion of hornblende and feldspar, the former being dark, the latter light, in color. The green of these stones is due to the chromium which is present. The "Palisades," the bluff skirting the western shore of the Hudson River, opposite and above New York, is composed of trap rock. Greenstone also is found in considerable quantities in the same locality, and in the Orange Mountain of New Jersey. These stones make a very durable building material, but cannot be obtained in large blocks, and are very difficult to cut. They form excellent metalling for macadamized roads, and the last two are especially useful for block pavement.

The Porphyries contain from 60 to 80 per cent. silica, 10 to 20 per cent. alumina, and the remaining constituents are iron-oxide, lime, magnesia, soda, and potash in small proportions, and have some value in construction. Their specific gravity ranges from 2.5 to 2.6. They are used principally for ornamental purposes. A fine quality of this stone is obtained near Boston.

7. Sedimentary Rocks.—*Sandstone* was formed in all of the later geological periods; it is a stratified rock, consisting of grains of sand derived from the disintegration of silicious rock, and cemented together by a natural cement composed usually of silica, lime, and alumina. In the most durable kinds of sandstone, this cement is found to be almost pure

* *School of Mines Quarterly* makes Trap the *generic* name for these rocks.

silica, and in the weaker stones it consists quite largely of alumina.

Lime, when present in this cement, renders the stone peculiarly liable to disintegration when exposed to an impure atmosphere, or when it is used for foundations washed by water containing acids capable of attacking the lime. The presence of clay (silicate of alumina) or of protoxide of iron, is very injurious.

8. **Sandstones** vary in quality between very wide limits, some being nearly as valuable as granite, and other kinds being the most friable of our building stones. A small grain, a minute proportion of cementing material, and a sharp, clear, bright fracture are the characteristics of the best stone. Such stone is usually found in thick beds, exhibiting but slight evidence of stratification.

Water readily penetrates between the layers of this stone. In foundations, care should therefore be taken to lay it on its "natural bed," that such penetration of moisture and consequent disintegration by freezing, may, as far as possible, be prevented.

The strength and durability of good sandstone, together with the ease with which it is cut and dressed, makes it the most commonly used of all our building stones. It is frequently denominated "free-stone," from the facility with which it is worked, and "brownstone" when of that color.

The colors of sandstones vary greatly. The Ohio or Amherst and Nova Scotia sandstones are of a yellowish or cream-color, or nearly white. Missouri furnishes a durable stone of a fine yellowish drab color. The stones from Portland, Connecticut; Newark, New Jersey; and from Marquette and Bass Islands in Lake Superior, are dark brownish red. A purplish red stone is found along the Rappahannock and Acquia Creek, which is, however, not of the best quality. A very hard and durable, highly silicious, reddish sandstone is obtained at Potsdam, New York. A dark brownish stone is found at Hummelstown, Pennsylvania.

9. **Soapstone,** the silicate of magnesia, is a very widely distributed stone in the United States, and is very valuable

where a stone capable of resisting high temperatures is required.

10. **Calcareous Stones** consist largely of lime; limestones and marbles are familiar examples.

Limestones—carbonates of lime—effervesce freely when attacked by acids which are capable of displacing carbonic acid from its combinations. The carbonic acid may also be expelled by high temperature. In the former case, new lime salts are formed by the union of the lime with the attacking acid; in the latter case, caustic lime, "quick-lime," is left uncombined. The limestones vary greatly in their qualities as building materials. While some are as strong and hard as granite, others are as soft and friable as the weakest sandstone. They are, usually, easily worked. There are two sorts: the granular and the compact; both of which classes yield excellent stones.

Those limestones which take a smooth surface and a fine polish are usually called marble; the coarser kinds are known as common limestone. The granular varieties are generally superior in quality, for building purposes, to the compact. The impure carbonates of lime are sometimes of great value. The magnesian limestones, or dolomites, are frequently found to be exceptionally excellent.

Chalk is a soft limestone in which pressure has not usually wholly destroyed the organic texture of the minute shells of which it is composed. It is generally too soft for constructive purposes, and can only be used for making lime.

All the varieties of calcareous stone are found in the United States, one of the most extensive deposits being that which follows a line parallel to the Atlanticc oast, and near the deposit of primary rocks already referred to; another underlies the Middle States. The marbles are mostly confined to mountainous districts; the common limestones are often found in immense strata as deposited on the bed of the ancient ocean.

11. **Marbles** are usually classified into white and colored, or variegated.

White marble is found in the Laurentian rocks of Canada. Most of the white marble used in the Northern Atlantic States comes from the Green Mountain range extending through Vermont, western Massachusetts, western Connecticut, and south-eastern New York. Valuable quarries exist in Vermont, at Brandon, Rutland, Danby, Dorset, and Manchester; in Massachusetts, at Lanesborough, Lee, Stockbridge, Great Barrington, and Sheffield; in Connecticut, at Canaan; and in New York at Pleasantville and Tuckahoe. Lee marble was used for the extension of the Capitol at Washington, and for the City Hall at Philadelphia. Pleasantville and Tuckahoe marbles were used for the St. Patrick Cathedral, New York. The Pleasantville quarries supply the "Snowflake" marble. A fine quality of statuary marble is found at Rutland, Vermont, which is almost equal to the Italian marble of Europe. The marbles become coarser, harder, and more suitable for building purposes as we proceed south from Rutland. In south-eastern New York they are of a dolomitic character. In Delaware is found a coarse dolomitic marble which resembles the Tuckahoe.

Colored marbles.—In Vermont, on the shore of Lake Champlain, is found a brecciated marble, and a dove-colored marble with greenish streaks is quarried at Rutland. Shoreham, Connecticut, supplies a black marble, and a fine marble of the same color is obtained at Williamsport, Pennsylvania. The black Trenton limestone is found at Glen Falls, New York. The Warwick marble from Orange Co., New York, is very beautifully colored with carmine in different shades, veined with white. The Knoxville marble is of a reddish hue, with lines of blue. The Tennessee so-called marble is mottled with chocolate and white.

Of foreign marbles, the best known are—the Brodliglio of Italy, in gray, shaded with black; the Sunna of Spain, a pale yellow; the Lisbon of Portugal, a pale reddish color; and the Belgian black of Belgium. Verde Antique is composed of bands of Serpentine and white marble.

The limestones are also of special interest in furnishing, by calcination, the several varieties of lime and cements.

12. **Common Lime** is obtained from the limestones of the middle and western States, from Maine and other States of New England; hydraulic lime is made in the State of New York; and many other localities furnish excellent lime or cement.

The limestones are indispensable to the iron-maker, also, as affording him an alkaline base, which, uniting chemically with the silica and alumina, and other impurities of the ores, allow the metal to separate in a state approximating purity; the silica and lime form the slag, which is also useful as a protecting covering over the molten iron, while it remains in the blast furnace. For such purposes a limestone free from magnsia or other impurity is generally most valuable.

13. **Gypsum, Alabaster, or "Plaster of Paris"** is a sulphate of lime, containing some water of crystallization. It takes the latter name from the fact that large deposits of this stone, of excellent quality, underlie the City of Paris and its environs.

When pure it contains, lime, 32.6; sulphuric acid, 46.5; water, 20.9. It is translucent and colorless. Its specific gravity is 2.6 to 2.8.

When raised to a high temperature, it loses its water of crystallization, and, if then finely powdered and made into a thin paste with water, it may be readily moulded and worked into any desired form. It then quickly "sets" or hardens. It is thus beautifully adapted for use in making casts and ornaments, and has recently been largely used in special branches of pattern making. It also makes an excellent cement for many purposes. The engineer uses it in making models and patterns, and for moulds which are not to be subjected to great heat.

This stone is found in many parts of our country. Considerable quantities are quarried in the State of New York.

14. **Argillaceous Stones** are of little value, as a rule, for the masons' work; they are generally weak, soft, and readily decomposed by the action of the weather.

Clay slate is a sedimentary, argillaceous rock, of fine-

grained, compact, and laminated structure, and is usually of dark shades of purple, blue, and green.

The best varieties of clay slate, or roofing slate, and of grauwacke-slate are used for roofing and flagging.

The former are obtained of remarkably fine quality in the State of Vermont; the latter, on the banks of the Hudson.

15. "**Fire-Stones**" are those capable of resisting the action of great heat, neither fusing, exfoliating, nor cracking.

Lime and magnesia, except where existing as silicates, are injurious in fire-stones.

Potash is very injurious, increasing the fusibility of the stone, and, melting, causing the formation of a fusible glass.

Quartz and mica, alone or in combination, make stones of great infusibility.

Mica-slate and gneiss are examples of excellent combinations, the latter, more particularly, when containing a considerable proportion of arenaceous quartz.

Limestones do not usually withstand the effect of heat well. The heat of the fire calcines it deeply where exposed, and thus destroys walls built of it. In the midst of great conflagrations, as at Chicago in 1871, the carbonic acid with which the lime is combined has been expelled so rapidly as to produce violent and explosive disruption. Magnesian limestones are little if any better than the pure limestones. Oleiferous limestones, containing silica and alumina, sometimes, however, resist fire moderately well.

Granite, gneiss, sienite, quartz, mica-slate, and other primary rocks usually contain some water; when exposed to fire, they crack and even explode. Walls constructed of these stones are apt to crumble rapidly in a hot fire.

Sandstones free from feldspar, somewhat porous and uncrystallized, are the most refractory of common building stones. Brick, especially when approximating to fire-brick in composition, is an excellent fire-resisting material, perhaps the best now known.

Concrete and béton, even when well made and completely set, and artificial stones consisting principally of silicates of

lime and alumina, are not generally very good heat-resisting materials.

Thin walls of any known building material will rapidly crumble in the midst of a large fire. The natural stones are less generally used where refractory materials are required, than are fire-brick, the characteristics of which latter will be described hereafter.

16. The Hardness of Stones is measured by comparison with some well-known stone of which the hardness is taken as a standard. The mineralogist's scale of hardness is the following, the softest being 1, and the hardest 10, on the scale.

TABLE I.

HARDNESS OF MINERALS.

Diamond	10	Lapis lazuli	6
Ruby	9	Feldspar	6
Cymophane	8.5	Amphibole	5.5
Topaz	8	Phosphorite	5
Spinell	8	Fluor-spar	4
Emerald	8	Coelestine	3.5
Garnet	7.5	Barytes	3.5
Zircon	7	Carbonate of lime	3
Quartz	7	Mica	2.5
Tourmaline	7	Gypsum	2
Opal	6	Chlorite	1.5
Turquois	6	Talc	1

The comparative resistance of stones to abrasion is as follows*:

TABLE II.

RESISTANCE OF STONES TO ABRASION.

Statuary marble	100.	Old Portland cement stone	79.
Bath stone	12.	Kilkenny black marble	110.
Stock brick	34.	Yorkshire paving stone	327.
Roman cement stone	69.	Aberdeen granite	980.

17. The Strength of Stone to resist Crushing varies

* *Journal Franklin Institute*, Oct., 1835.

immensely with different classes, and often very considerably even in the same class. Gen. Q. A. Gillmore has shown that under a maximum varying for each specimen, the resistance varies as the cube root of the length of the side of cubes experimented on. The densest stones are usually strongest.*

For Berea sandstone, Gilmore gives $y = a\sqrt[3]{x}$, in which y = crushing resistance per square inch of surface in pounds; x = the length of the side of the cube in inches, and a = from 7000 to 9500. (For metric measures: kilogrammes per square centimetre and centimetres, a = 350 to 500).

TABLE III.

STRENGTH OF STONES UNDER COMPRESSION.

NAME.	KILOGRAMMES PER SQUARE METRE.	TONS PER SQ. FT.
Granite and sienite	7,655,000 to 10,936,000	700 to 1000
" " " good quality	9,842,000	900
Basalt and trap	8,749,000	800
Limestone and marble	3,827,500 to 7,655,000	350 to 700
Best sandstone, average	5,468,000	500
Conn. and New Jersey sandstone, ordinary.	3,827,500	350
Slate	2,187,000 to 5,468,000	200 to 500

Trautwine takes the average weight of granite at 165 pounds per cubic foot (about 2643 kilogrammes per cubic metre), and of ordinary sandstone at 145 pounds per cubic foot (2323 kilogrammes per cubic metre), and calculates the height of column it would stand without crushing at the base as 8000 feet (2440 metres), and 4000 feet (1220 metres) respectively, for these two kinds of stone.

The weight imposed ordinarily on foundations of structures is rarely ten tons per square foot (109,360 kilogrammes per square metre). Stones of a soft quality usually begin to

* *Journal Franklin Institute*, Vol. LXV., p. 336.

crack at not far from one-half their crushing loads. The hardest stones yield suddenly and completely when the crushing load is reached. Stones crush most easily under soft materials, and offer most resistance between surfaces of hard steel. Polished stones resist better than rough.

18. Transverse Strength. — Experiments made upon building-stones by Mr. R. G. Hatfield are recorded in the Transactions of the American Society of Civil Engineers for 1872 *et seq.* The formula $W = S\frac{bd^2}{L}$ is used in expressing transverse strength. S = weight in pounds required to break a bar one inch square and one foot long between bearings; L = length in feet; b and d measure the breadth and depth of the sample in inches.

The coëfficient, S, varies from 250.76 to 227.19 for Hudson River blue-stone; for Kingston it is 203.50; for other specimens of blue-stone or grauwacke the coëfficient falls as low as 122.31. Marble from East Chester gives about 150. Sandstone from Belleville, New Jersey, gives coëfficients varying from 76 to 88.472; from Portland, Connecticut, 64.7 to 94; from Dorchester, Nova Scotia, 63 to 67. Ohio light sandstones give from 32 to 62.

For weights in kilogrammes, lengths in metres, and breadth and depth in centimetres, the values of S become eight one-thousandths those above given.

The *factor of safety* should never be less than ten, and a far higher value is adopted in practice by many experienced engineers. At the same time, it should be remembered that the crushing strength of the mortar or cement, used as the binding material, in many cases, rather than the strength of the stone itself, determines this limit.

19. The Durability of Stones varies as greatly as do their other qualities. It is determined by strength, hardness, and porosity. Experience and careful observation are the most reliable guides in judging of durability; but a series of carefully conducted tests may be made to yield valuable aid in estimating the values of newly opened quarries. In all important work a careful test should be made of the stone pro-

posed to be used. The quantity of water absorbed gives a good comparative test of the durability of stones of the same class, as does also their greater or less clearness of sound when struck with a hammer.

The following are the percentages of their own weight absorbed by different stones:

Granite absorbs from	$\frac{1}{8}$	per cent.	to	1	per cent.	of	water.		
Gneiss	"	"	1	"	"	"	$2\frac{1}{2}$	"	"	"	"
Sandstone	"	"	$1\frac{1}{2}$	"	"	"	3	"	"	"	"

Fine-grained stones absorb least water, and are usually hardest and best.

*M. Brard's method** of determining power of resisting the action of frost, is as follows: A cubical block, containing about 8 cubic inches (131 cubic centimetres), is sawn from a stone to be tested. This is suspended in a boiling supersaturated solution of sodic sulphate during a period of thirty minutes. It is then taken out, suspended above the liquid, and allowed to cool. This is repeated daily, or oftener, for at least a week. The crystallization of the salt within the pores of the stone disintegrates it, precisely as does the action of frost. The weights of the specimens tested are carefully taken before and after the test, and their comparative value is thus learned.

The chemical composition of stones greatly affects their durability. Potash is apt to wash out, leaving the stone soft and friable; clay absorbs water and thus softens stones of which it is a constituent; and iron, as has already been stated, injures by discoloration, and by the disintegration produced by changes from protoxide to peroxide.

Hatfield gives the following as the result of his examination of building-stones:

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* Annales de Chimie et de Physique, vol. xxxviii.

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TABLE IV.

DURABILITY OF STONES.

NO.	NAME.	LOCALITY.	WEIGHT PER CU. FT. POUNDS.	DURABILITY — YEARS REQUIRED TO DISINTEGRATE TO THE DEPTH OF $\frac{1}{10}$ INCH. (0.254 C. M.)
1	Sandstone.....	Portland, Conn ..	150.41	2003.3
2	"	Berea, Ohio	134.14	2000.8
3	"	Marietta, Ohio...	161.94	1794.8
4	"	Dorchester, N. S.	140.52	811.40
5	"	Amherst, Ohio...	133.16	306.46
6	Coquina.....	Florida.....	105.76	6.92

20. Effect of Heat.—Expansion by heat takes place as follows, the range of temperature being 180° Fahr. (100° Cent.):

Granite and sienite 0008
Sandstone.....0006 to .0010.

Mr. H. A. Cutting, State Geologist of Maine, experimenting upon the granites, finds that their specific gravity varies from 2.50 to 2.83; that their power of absorption of moisture decreases irregularly with increase of density from 0.00300 to 0.00125, although the heaviest stones are not invariably least penetrable; that they are uninjured when heated to 500° F. (260° C.) and plunged into water, but that they are all injured at temperatures below the red heat; that at the latter temperatures they often crumble and become entirely worthless. The common sandstones vary in specific gravity from 2.2 to 2.6; they usually absorb from 0.06 to 0.25 water, although occasionally as little as 0.025, and withstand heat better than the granites, bearing temperatures 100° F. (55° C.) higher with equal safety.

The limestones examined compared favorably with the sandstones. Conglomerates are not equal to either of the former sorts. "Soapstone" withstands heat much better

than any other stone tested, receiving no apparent injury up to 1,200° F. (649° C.).

21. **Artificial Stones** comprise brick of various kinds, concrete, béton, and artificial imitations of sandstone.

22. **Bricks** are made by submitting clay, which has been prepared properly and moulded into shape, to a temperature which converts it into a semivitrified stone.

Common brick is a most valuable substitute for stone. Its comparative cheapness, the ease with which it is transported and handled, and the facility with which it is worked into structures of any desired form, are its valuable characteristics. It is, when properly made, nearly as strong as good building-stone; it is but slightly affected by change of temperature, or of humidity, is well cemented by mortars, and is also lighter than stone.

23. **Common Clays**, of which the common brick is made, consist principally of silicate of alumina; but they also usually contain, lime, magnesia, and oxide of iron. The latter is useful, improving the product by giving it hardness and strength; hence, the red brick of the Eastern States is often of better quality than the white and yellow brick made in the West. Silicate of lime renders the clay too fusible, and causes the bricks to soften and to become distorted in the process of burning. Carbonate of lime is certain to become decomposed in burning, and the caustic lime left behind absorbs moisture and promotes disintegration.

Uncombined silica is beneficial, if not in excess, as it preserves the form of the brick at high temperatures. In excess, it destroys cohesion, and renders the bricks brittle and weak. Twenty or twenty-five per cent. silica makes a good proportion.

Preparing the clay consists in clearing it carefully of pebbles, and after mixing it with about one-half its volume of water, "tempering" it either in a "pug-mill" or by hand stirring.

The clay is moulded into bricks by pressing it into forms, either by hand or by a machine, and they are then piled and burned, after having been well dried in the open air.

Burning occupies about two weeks. The bricks are first subjected to a moderate heat, until all remaining moisture has been expelled. The heat is then increased slowly, until, at the end of twenty-four hours, the "arch-bricks" attain a white heat; the temperature is then lowered somewhat, and a moderately high furnace heat is kept up until the burning is complete. Finally, all openings are closed, the fire is smothered, and the mass is then very slowly cooled.

In the more modern processes of burning brick the principal yards have permanent kilns built of brick, either circular or in the form of an ellipse, and made in compartments, each of which has a separate entrance and independent connection with the chimney. A down draught is secured from the top, where the fuel is placed, to the chimney, which is either built within the kilns or entirely outside, but which has its draught invariably connected with the bottom of the kilns. The fuel used is generally fine coal, which falls around the bricks, and the flame and heated gases surround and pass through all portions of the materials being burned. While some compartments are being burned, others are being filled, and still others are being emptied.

Bricks of three kinds are taken from the kiln. Those forming the top and sides of the "arches" in which the fire is built are overburned and partially vitrified. They are called "*arch-bricks*," are hard, brittle, and weak. Brick from the interior of the pile are called "*body-bricks*," and sometimes *hard* or *cherry brick;* they are of the best quality. Those brick which have formed the exterior of the mass are underburned, and are called *soft*, *sammel*, or *pale* brick. They are too soft, and are of insufficient strength for use, except for filling, in even ordinary work. Their price in the market is about twenty per cent. less than body brick, and variable.

24. **Good Bricks** should be of regular shape, with parallel surfaces, plane faces, and sharp edges and angles. They should exhibit a fine, compact, uniform texture, should be

quite hard, and should ring clearly when struck a sharp blow. They should absorb not more than six per cent. of their weight of water.

Brick of fair quality bears a compressive force of 3,000 pounds on the square inch (211 kilogrammes per square centimetre) without completely crushing.* Very soft bricks will yield at as low a pressure as one-eighth this amount; while the very best of pressed brick have been known to bear more than double 3,000 pounds.† Good brick may be taken to average about 2,000 pounds per square inch (141 kilogrammes per square centimetre.) Trautwine takes a minimum crushing strength for red brick at thirty tons per square foot (328,060 kilogrammes per square metre), and their weight at 112 pounds per cubic foot (1,794 kilogrammes per cubic metre) and thus estimates that a vertical column 600 feet (183 metres) high, would just crush at the base under its own weight. The experiments of Hatfield upon the transverse strength of brick gives a value for S in the formula $S = \frac{L\,W}{b d^2}$, of from 19.6 to 26.36 for Perth Amboy; of from 24.35 to 42.74 for Hudson River hard brick; and of from 32.29 to 41.85 for Philadelphia pressed brick. (In using metric measures, S becomes eight one-thousandths of these values as before.)

Masses of brickwork crush under smaller loads than single bricks; and first quality brick, laid in first quality cement, should not be subjected to much above ten tons per square foot (11 kilogrammes per square centimetre) as a permanent load.

The size and weight of bricks vary considerably. The British legal standard is $8\frac{3}{4} \times 4\frac{3}{8} \times 2\frac{3}{4}$ inches. In the United States, $8\frac{1}{4} \times 4 \times 2\frac{1}{4}$ is a usual size. Brickwork may be estimated at an average weight of 116 pounds per cubic foot. A good bricklayer lays from 100 to 200 bricks an hour, according to the character of the work.

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* G. S. Greene, *Journal Franklin Institute*, Vol. LXV., p. 332.

† The author has tested specimens capable of resisting more than 10,000 pounds per square inch, (703 kilogrammes per sq. cm.).

The following averages are given:

DESCRIPTION.	INCHES.	DESCRIPTION.	INCHES.
Baltimore front.....	$8\frac{1}{4} \times 4\frac{1}{8} \times 2\frac{3}{8}$	Maine.....	$7\frac{1}{2} \times 3\frac{3}{8} \times 2\frac{3}{8}$
Philadelphia "		Milwaukee.....	$8\frac{1}{2} \times 4\frac{1}{2} \times 2\frac{3}{8}$
Wilmington "	.. .. ..	North River.....	$8 \times 3\frac{1}{2} \times 2\frac{1}{4}$
Croton "	$8\frac{1}{2} \times 4 \times 2\frac{1}{4}$	Ordinary	$7\frac{1}{2} \times 3\frac{3}{8} \times 2\frac{1}{4}$
Colabaugh.....	$8\frac{1}{4} \times 3\frac{5}{8} \times 2\frac{3}{8}$		$8 \times 4\frac{1}{2} \times 2\frac{1}{2}$
Stourbridge fire-brick.....			$9\frac{1}{8} \times 4\frac{5}{8} \times 2\frac{3}{8}$ inches.
American (N. Y.).....			$8\frac{7}{8} \times 4\frac{1}{2} \times 2\frac{5}{8}$ "

25. Fire-brick is used whenever very high temperatures are to be resisted. They are made either of a very nearly pure clay—silicate of alumina—of a mixture of pure clay with clean sand, or, in rare cases, of nearly pure silica cemented with a small proportion of clay. The presence of oxide of iron is very injurious, and it has been accepted as a rule by good engineers, that the presence of six per cent. ferric oxide in the brick justifies its rejection. It should generally be stipulated that fire-brick proposed for purchase should contain less than six per cent. of oxide of iron, and less than an aggregate of three per cent. of combined lime, soda, potash, and magnesia. The sulphide of iron—pyrites—is even worse in its effect on fire-brick than the substances just named.

Where intended to resist extremely high heat simply, silica should be in excess; and where exposed to the action of metallic oxides, which would tend to unite with silica, alumina should be in excess.

Good fire-brick should be uniform in size, regular in shape, homogeneous in texture and composition, easily cut, strong and infusible. A good bricklayer should lay sixty per hour.

The strength of fire-brick, as determined by experiments at the Royal (British) Arsenal, in 1871, is sufficient to enable it to sustain from 900 up to 2,000 pounds per square inch (63 to 141 kilogrammes per square centimetre) before crushing. Bricks tested by the author have usually borne the maximum figure and often exceed it two or three times.

Excellent fire-brick is made at Newark, South Amboy, and other places in New Jersey. The most infusible known fire-bricks are the Welsh Dinas bricks, which consist of 97 per cent. silica and 3 per cent. alumina and other constituents. The Mount Savage brick, of Maryland, U. S., is also noted for its infusibility.

In lead smelting furnaces preference is given to fire-brick made of kaolinitic clay.

Retorts for gas manufacturers, for glass-makers, and for other purposes, are made of fire-clay, in a similar manner to fire-brick, but they necessarily require more care in selecting materials, in moulding, and, particularly, in baking.

A celebrated fire-clay has the following composition :

SAMPLE.	SILICA.	ALUMINA.	PROT. IRON.	LIME.	MAGNESIA.	POTASH.
Sample 1.....	59.87	33.49	3.01	1.42	0.31	2.21
Sample 2.....	67.69	27.91	2.35	0.63	0.11	....
Sample 3.....	70.32	26.42	1.04	0.36	0.43	1.40

It makes excellent fire-bricks and crucibles, burns perfectly white, and makes a fine glass-house clay.

26. **Artificial Sandstones** are made by several processes. Of these béton and concrete will be referred to after explaining the methods of making mortars and cements.

27. **Mortars and Cements** are used in masonry for the purpose of uniting the natural and artificial stones. They usually, when completely hardened or "set," consist wholly or partially of carbonate of lime united with sand, or with sand and clay. Plaster of Paris—sulphate of lime—is also sometimes used. Carbonate of lime is formed by the absorption of carbonic acid from the atmosphere, which unites with the lime with which the mortars and cements were originally made up.

In the structures of the ancient Egyptians, as in the Great Pyramid, mortar was freely employed; but it consisted almost entirely of sulphate of lime. A specimen taken from an ancient Phœnician temple, the highest stone of which was,

a few years ago, five feet below the level of the ground, was quite similar to that found in some of the castles in Europe, and was like a piece of solid rock. It was made of burnt lime, fine sand, coarse sand, and gravel. It was a concrete rather than a mortar; the lime had become completely carbonated. Ancient Greek mortars from ruins in the neighborhood of Athens are in very perfect condition; they contain no gravel. Mortars from ruined buildings in Herculaneum, and from Rome and its vicinity, appear to have been made from burnt lime and puzzolana, or volcanic ash.

28. **Lime,** as a building material, is of three principal kinds: *common or air lime, hydraulic lime, and hydraulic or water cement.*

Common lime, called also pure, rich, or fat lime, is produced by calcining limestone, which is nearly pure carbonate of lime, and thus expelling its carbonic acid.

It "slakes" by greedily absorbing moisture, becoming converted into a dry hydrate, if water is not used to excess. Made into a paste with water, it hardens slowly in the air, but not at all under water.

29. **Hydraulic Limes** are made from stones containing from 18 to 30 per cent. of silicate of alumina, of carbonate of magnesia, or of a mixture of both. They slake more slowly than air lime, and the paste hardens very slowly under water, or in wet localities.

Hydraulic cements are made by calcining limestones containing from 30 to 60 per cent. of clay. They do not slake, and their pastes harden with rapidity under water. They are, therefore, of greatest use in building foundations. Where the proportion of silicate of alumina is greater than 60 per cent., the material is called *puzzolana,* and it requires the addition of fat lime to render it useful. Natural puzzolana is of volcanic origin. Brick-dust has a similar power of rendering fat limes hydraulic, as has also trass, terras, or blue trap-rock.

The hydraulic limes and cements are sometimes obtained from stones which contain the desired proportion of limestone and clay; in which case they are known as ***natural***

limes or cements. Sometimes the lime and the clay are mixed artificially in proper proportions.

Limestones of all qualities are found in New England, New York, and many other portions of the United States.

The English Portland cement is made by grinding together chalk and clay. That from the gray chalk is said to be heaviest and best. This is the strongest cement known in the market, and it is by far the most expensive.

Roman cement is made from nodules of limestone containing clay and iron. It makes a cement which sets more quickly than the Portland, but does not become as hard.

30. **Mortars** are made by mixing lime and sand with water in such proportions as will give the desired quality, thus forming a paste which may be used for uniting stone and brickwork.

Common Mortar is made with fat lime, and clean, sharp sands, in the proportions, usually, of 1 to 5 by volume.

It hardens promptly in the air, and becomes, finally, very hard, if of good quality, and if frost, or too great dryness, or excessive dampness does not injure it while setting.

Hydraulic mortar is made with hydraulic lime and sand. It hardens in damp situations, and is a strong binding material. Under water it often requires weeks to harden; but hydraulic mortar of fair quality requires from three or four days to a week. Very excellent varieties harden in from one to four days. It is often tempered with clay or lime to retard its setting. The slower this action, usually, the firmer and harder does the mortar finally become.

Hydraulic cement is a mortar made with the very hydraulic lime, also termed cement, already described. Hydraulic cements sometimes set in a few minutes after mixture, if warm; they do not shrink much in setting, and are often used without admixture of other material. Where even slight shrinkage is objectionable, an addition of three times its own volume of sand will prevent change of volume. Hydraulic cement is generally indispensable in the construction of foundations. It should be laid in thin joints, and should generally, if great strength is desired, be used un-

mixed with sand; it requires about one-third its volume of water.

The sand used in mixing mortars should be free from clay and perfectly clean; it should be sharp and rather coarse. River sand is usually found to be better than sea sand, as it is free from salt, and is less liable to be found water worn.

Mortars and cements are given different proportions for different kinds of work. Mortar for stone may be made by mixing 15 to 20 per cent. cement, 6 to 8 parts lime, and the remainder of the 100 parts sand; mortar of good quality for brickwork should contain 10 per cent. less sand. Stucco is made of two parts sand to one part cement; to this is sometimes added a little sugar or molasses.

Plaster for inside finish is usually of several grades. Coarse plaster is made by adding to common mortar about five per cent. of its volume of cows' hair; "fine stuff," or putty, is a paste of lime mixed without sand; "hard-finish" contains of lime 3 or 4 volumes, of plaster of Paris 1 part.

31. **Concrete** is made by mixing gravel or broken stone with lime and sand, using a limited amount of water. Fragments of brick are often also added.

It is mixed in about the proportion of 1 part lime, by volume; 6 parts or more of sand and other solid components, and 1½ parts water. In using it, it should be thoroughly mixed and carefully rammed in place. It swells about three per cent. in setting. Each cubic foot (.028 cubic metre) of gravel makes about four-fifths of a cubic foot (.022 cubic metre) of well rammed concrete.

Used as a foundation for masonry, it should be laid in layers of about a foot in thickness, each being carefully rammed before another is added. It is not well fitted for use in damp localities.

Béton is the name usually applied by engineers to a concrete in which hydraulic lime or cement is used, instead of fat lime. It should always be given the preference in wet, or even in damp, situations; and is often used on dry work also, when strength is sought.

Occasionally a little lime is added to retard the setting of strong hydraulic cement concrete.

A commission reporting on the submarine work of the New York Dock Commission states that in order to produce good submarine masonry by depositing freshly mixed concrete under water, certain precautions are necessary, viz.:

The cementing material should possess the properties of unctuousness and adhesiveness, to enable it to retain the sand while the concrete is assuming a state of rest in the water; and it should be capable, as much as possible, of assuming that state by spreading, rather than by breaking down and rolling off on the sides of the mass deposited.

If it be deficient in the properties last named, it should then be quick-setting, in order that the washing out of the sand from the cement may be arrested in a few minutes after deposition by its prompt hardening.

If a box is used for depositing the concrete, the shape of the box, and the method of emptying it, should be such that the concrete will be subjected to as little wash as possible. Hence a large box is preferable to a small one, as it will expose a less area of surface in proportion to the volume deposited.

Béton has been used in the following proportions on the works named, with excellent results:

Croton Aqueduct, New York—New York cement, 1 part, by volume; sand, 3 parts; broken stone, small enough to pass through a ring 1½ inches (3.8 centimetres) in internal diameter, 3 parts;—Cherbourg Breakwater, France—Portland cement, 1 part; sand, 3 parts.

Properly made, this concrete, or béton, is found to be strong enough to take the place of stone; walls, chimneys, and even bridges have been constructed of it.

The addition of a small quantity of sulphuric acid, or the presence of a sulphate, is found to add very considerably to the strength of mortars.

32. **Béton-Coignet,** as made by the French engineer, M. F. Coignet, and which attracted much attention at the International Exposition at Paris, in 1867, is composed of: lime, 4 parts; hydraulic cement, 1 to 2 parts; and sand, 20 parts.

The ingredients are first thoroughly intermixed dry, by hand, and again in a mill, moistening them very slightly with clean water. Moulds are then filled with the mixture, and it is compacted by ramming or hammering

Four bushels of the mixture, occupying, when dry, five cubic feet (141.6 litres), make three cubic feet (85 litres) of finished work, weighing 140 pounds per cubic foot (2,243 kilogrammes per cubic metre). Its peculiarities are the small quantity of water used in its manufacture, and the thoroughness with which the mixing and ramming are done. It sets quickly, is very strong, and is the best example of mixed béton.*

It may be made into blocks to be used as cut stone, or may be built up in masses of any desired shape. The cheapness and strength of construction of Béton-Coignet are so remarkable as to have led to its use for even ornamental work. It is used to a considerable extent in constructing the walls of houses and public buildings.

33. Strength of Mortars, Cements, and Concrete.— Mortar has a tenacity of from 6 to 34 pounds per square inch (0.42 to 2.39 kilogrammes per square centimetre) when six months old; and the average, as determined by General Totten, U. S. A., was about 15 pounds per square inch (1.05 kilogrammes per square centimetre), or nearly a ton per square foot (10,937 kilogrammes per square metre).

The increase in strength, with age, is very variable, amounting sometimes to twice or three times these figures, and, at other times, to a mere fraction.

The resistance to crushing, a year and a half after setting, is given by Rondelet as from 440 to 580 pounds per square inch (31 to 41 kilogrammes per square centimetre) when simply laid in place; and from 600 to 800 pounds (42 to 56 kilogrammes) when well rammed. These figures correspond to about 30 and 35, 40 and 50 tons, respectively, to the square foot (328,066 and 382,750, 437,450 and 546,800 kilogrammes per square metre).

Its adhesion to brick or stone work is about equal to its

* See Reports U. S. Commission to Paris Exposition, 1867, and Gilmore on Béton-Coignet.

cohesive strength, where the work is well done; and old mortar has sometimes so great adhesion and cohesion as to allow the brick itself to be fractured without rupturing the mortar.

Cement used at Cherbourg, after nine months, was found to bear a compression of over 100 tons per square foot (1,093,684 kilogrammes per square metre), and to have a cohesive strength of 200 pounds per square inch (14 kilogrammes per square centimetre). Cement without sand should acquire, in six months, a tenacity of 50 pounds per square inch (3.50 kilogrammes per square centimetre), and a compressive resistance of more than 100 tons per square foot (1,093,684 kilogrammes per square metre). Made into prisms of 8 inches in length by 2 inches square (20.3 × 5.1 centimetres), the best qualities break with a weight at the middle of their length of about 1,000, and sometimes 1,500 pounds (454 and 682 kilogrammes), while the poorer qualities yield under 500 pounds (227 kilogrammes).

Mr. Edmund Yardley, in experiments reported to the American Society of Civil Engineers, in June, 1872, tested the transverse strengths of a number of hydraulic cements of various ages. He found the "Allen" cement, from Easton, Pa., when made into prisms 1 inch (2.539 centimetres) square and 6 inches (15.2 centimetres) long, to have a breaking weight, at the middle, of about 40, 60, and 90 pounds (18.2, 27.2, 40.9 kilogrammes), at 1, 3, and 6 months' age, if without sand, and nearly the same where mixed 1 part sand to 2 of cement. "Rosendale" gave way with 27, 63, and 67 pounds (12.3, 28.6, 30.5 kilogrammes), at similar ages, when used alone, and 35, 62, and 110 (15.9, 28.2, 50 kilogrammes), when mixed with one-half its volume of sand. "Diamond" bore, at the same ages, 30, 35, and 85 (13.6, 15.9, 38.6 kilogrammes), without sand, and 27, 55, and 91 (12.2, 25, 41.3 kilogrammes), with 1 part sand to 2 of cement. Sand added in the proportion of 2 parts to 1 of cement gave far less favorable results.*

* See a paper by Maclay, Trans. Am. Soc. Civil Eng., 1877, for a very full compendium relating to the strength of cements. Also, *Scientific American*, supplement, No. 113.

Gypsum, "*Plaster of Paris*," which is often used as a cement, has a tenacity, according to Rondelet, of 70 pounds per square inch (5 kilogrammes per square centimetre). It is frequently mixed with lime in the manufacture of mortars, and sometimes with concrete.

Dr. Wallace, F.R.S.E., examined the mortar of the Great Pyramid of Egypt, and found it to contain 80 to 90 per cent. sulphate of lime.

He gives the following analysis of one specimen:

Hydrated sulphate of lime	92.83
Carbonate of lime	4.63
Carbonate of magnesia	1.66
Alumina and traces of oxide of iron	.24
Silica	.88
Water (hygroscopic)	.07
	100.31

The following are analyses of two specimens examined a few years earlier:

Hydrated sulphate of lime	81.50	82.89
Carbonate of lime	9.47	9.80
Carbonate of magnesia	.59	.79
Oxide of iron	.25	.21
Alumina	2.41	3.00
Silica	5.30	4.30
Water	....	....
	99.52	100.99

Dr. Wallace states that he believes that the sulphate of lime, which is abundant near the Pyramids, was partly calcined to drive off the water of hydration in the mineral before it was used in making the mortar.

Plaster of Paris is used for a hard finish to walls, and for the moulding of cornice ornaments, for which latter purpose, to prevent its too rapid setting, it is usually mixed with a small proportion of slaked lime.

The addition of two per cent. of alum or borax to calcined gypsum delays its setting three or four hours, but the material then becomes a stone-like body, heavier than ordinary plaster. Cements made in this way are known as Parian. Plaster of

Paris is largely used in taking casts, and in stereotyping. Gypsum is also employed for glazing porcelain, and, being an excellent non-conductor of heat, with alum for filling fire-proof safes. Made into a mortar with sand and lime, it is used for cementing floors and vaults.

The best gypsum quarries that are worked on this continent are those of the Bay of Fundy, Nova Scotia, and Hillsboro, New Brunswick. Over one hundred thousand tons of the finest quality have been annually imported from these places into the United States.

34. **The Bituminous Cements** are usually composed of mixtures of bituminous substances, as asphalt, with less costly materials. Bitumen or mineral tar, asphalt, and a bituminous limestone are thus used. The latter sometimes contains ten or fifteen per cent. bitumen.

The mixtures are made by breaking up the materials, and heating them in large iron kettles or boilers. The proportions in mastic are usually from one to one and a half parts bitumen to each ten of asphalt.

Coal-tar, although of far inferior value, is frequently used instead of the natural bitumen, as is also pitch.

Fire-clay is sometimes used in place of limestone, and the preparation so made makes excellent joints for water-pipes.

Bituminous cements mixed with broken stone to form a bituminous concrete sometimes make a good road covering.

35. **Masonry** is the art of making structures of stone, brick, or other earthy materials.

Good masonry is built in "courses," which are usually perpendicular to the lines of pressure bearing upon them, with discontinuous or "broken" joints in the lines of stress. The stone-mason selects the heaviest stones for his lowest courses in all foundations or structures, lays all stones on their natural beds, and secures the most perfect union between them and the cementing material.

The nomenclature of stone masonry has been revised by a committee of the American Society of Civil Engineers,* and

* Trans., No. CLI., 1877.

the specifications of the engineer are recommended to be made in accordance with that report and as below.

Stones are classed thus:

In practice, one class merges into the next.

I. *Unsquared Stones or Rubble.*—This class includes stones used as they come from the quarry, without other preparation than the removal of sharp angles and projections. The term "backing," frequently applied to this class of stone, properly designates material used in certain relative positions in the wall; while stones of this kind may be used in any position.

II. *Squared Stones.*—This class includes stones roughly squared and dressed on beds and joints. The dressing is done with the face hammer or the axe, or, in soft stones, with the tooth hammer. On gneiss, the point is sometimes used. Where the dressing on the joints is such that the average distance between the surfaces of adjoining stones is one-half inch or more, they properly belong to this class.

Three subdivisions of this class may be made, depending on the character of the face of the stone.

(*a.*) Quarry-faced stones are left untouched as they come from the quarry.

(*b.*) Pitch-faced stones have the arris clearly defined by a line beyond which the rock is cut away so as to produce edges approximately true.

(*c.*) Drafted stones have the face surrounded by a chisel draft, the space inside the draft being left rough. Ordinarily this is done only on stones in which the cutting of the joints is such as to exclude them from this class.

In ordering stones the specifications should state the width of bed and end joints, and how far the surface of the face may project beyond the plane of the edge. In practice the projection varies between 1″ and 6″. It should be specified whether the faces are to be drafted.

III. *Cut Stones.*—This class includes all squared stones with smoothly dressed beds and joints. As a rule, all the edges of cut stones are drafted, and between the drafts the stone is smoothly dressed. The face, however, is often left rough, when the constructions are massive.

The following are usual methods of dressing stones:

Rough-Pointed.—When necessary to remove an inch or more from the face of a stone, it is done by the pick until the projections vary from ½″ to 1″. The stone is then said to be rough pointed. This is the first operation in dressing limestone and granite (Fig. 1).

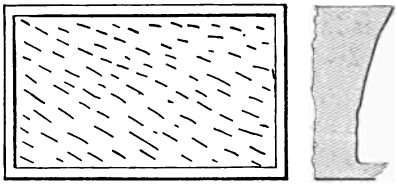


FIG. 1.

Fine-Pointed.—When a smoother finish is demanded, rough pointing is followed by fine pointing (Fig. 2). It is used where the finish is to be final, and not as a preparation for final finish by other tools.

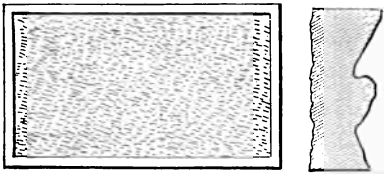


FIG. 2.

Crandalled.—This is a rapid method of pointing, the effect is the same as fine pointing, except that the marks on the stone are more regular. The variations of level are about ⅛″, and the rows are parallel. When other rows, at right angles to the first, are introduced, the stone is said to be *cross-crandalled* (Fig. 3).

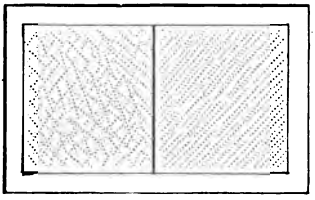


FIG. 3.

Axed or Pean Hammered, and Patent Hammered.—These vary only in the degree of smoothness of the surface (Fig. 4).

The number of blades in a patent hammer varies from 6 to 12 to the inch, and in specifications the number of cuts to the inch is stated, such as 6-cut, 8-cut, 10-cut, 12-cut. The effect of axeing is to cover the surface with chisel marks which are made parallel as far as practicable. Axeing is a final finish.

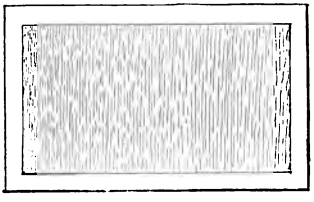


FIG. 4.

Tooth-Axed.—The tooth-axe is practically a number of

points and it leaves the surface of a stone in the same condition as fine pointing. It is usually a preparation for bush hammering, and the work is then done without regard to effect, provided the surface of the stone is sufficiently levelled.

Bush Hammered.—The inequalities of a stone are pounded off by the bush hammer, and the stone is then said to be "bushed" (Fig. 5). Sandstone thus treated is very apt to scale.

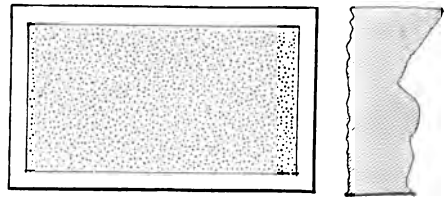


FIG. 5.

In dressing limestone which is to have a bush-hammered finish, the usual order of operations is: 1st, rough pointing; 2d, tooth axeing; 3d, bush hammering.

Rubbed.—In dressing sandstone and marble, it is very common to give the stone its surface at once by the use of the stone saw. Any inequalities left by the saw are removed by rubbing with grit or sandstone. These stones are used in architecture for string courses, lintels, door jambs, etc., and are well adapted for use in localities where a stone surface is liable to be rubbed by vessels or other moving bodies (Fig. 6).

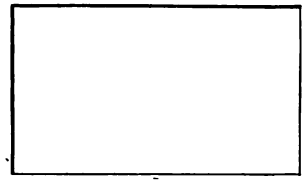


FIG. 6.

Diamond Panels.—The space between the margins is sunk immediately adjoining them, and thence rise the four planes forming an apex at the middle of the panel; this makes a sunk diamond panel. When the surface of the stone rises gradually from the inner lines of the margins to the middle of the panel, it is called a raised diamond panel (Fig. 7).

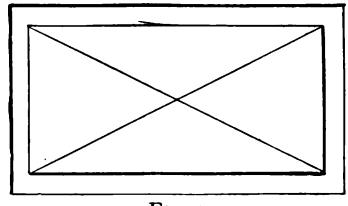


FIG. 7.

The term stone masonry includes:

(1.) *Rubble Masonry* is composed of unsquared stones; it may be Uncoursed Rubble (Fig. 8), laid in irregular courses,

or Coursed Rubble (Fig. 9), levelled off at specified heights. The stone may be required to be roughly shaped with the hammer, so as to fit fairly.

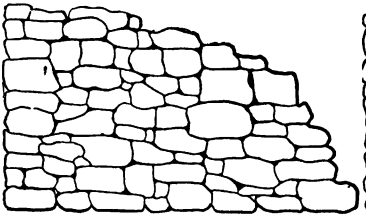


FIG. 8.

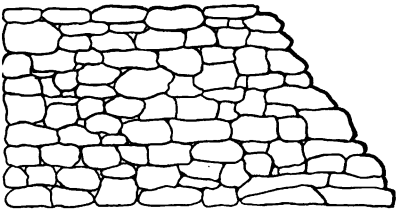


FIG. 9.

(2.) *Squared Stone Masonry.*—This is classified as Quarry-faced (Fig. 10), or as Pitch-faced (Fig. 11). If laid in regular

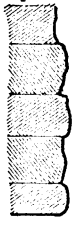


FIG. 10.

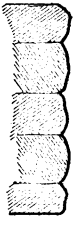


FIG. 11.

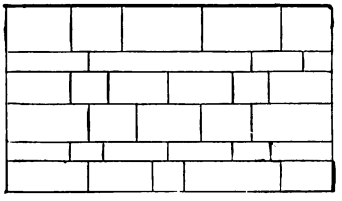


FIG. 12.

courses, it is Range work (Fig. 12). If laid in courses that are not continuous throughout the length of the wall, it is Broken Range work (Fig. 13). If not laid in courses, it is Random

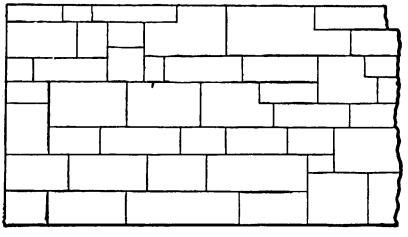


FIG. 13.

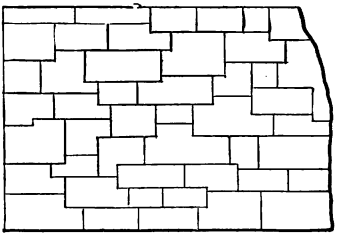


FIG. 14.

work (Fig. 14), and this is generally the method adopted.

In quarry-faced and pitch-faced masonry, quoins and the sides of openings are hammer-dressed, in removing projections to secure a rough-smooth surface, with the face hammer, the

plain axe, or the tooth axe. This is done for doors or window-frames, and improves the general effect if used where a corner is turned.

(3.) *Ashlar Masonry.*—This is "cut-stone masonry," or masonry composed of any of the kinds of cut stone. The courses are continuous (Fig. 15), but sometimes are broken

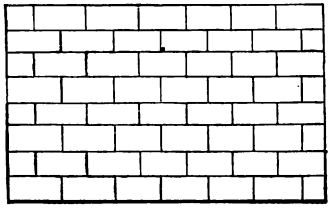


FIG. 15.

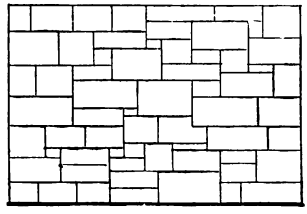


FIG. 16.

by the introduction of smaller stones; it is called Broken Ashlar (Fig. 16). If the stones are less than one foot in height, the term Small Ashlar is proper. The term Rough Ashlar is sometimes given to squared stone masonry when laid as Range work; but it is better to call such masonry "Squared Range work."

Dimension stones are cut stones, whose dimensions have been fixed. Specifications for Ashlar masonry prescribe the dimensions to be used.

36. General Rules.—Range work is usually backed up with Rubble masonry, which is specified as coursed Rubble.

Every specification should contain an accurate description of the character and quality of the work desired. Samples of cutting and masonry should be prepared beforehand.

The softer stones should have a depth equal to at least one-third their length to prevent crossbreaking, and a breadth of one-half their length. The hard and strong stones are allowed a double length. A rough natural surface is of advantage when strong adhesion of mortar is important. The thickness of joints in Ashlar masonry is about $\frac{1}{8}$ inch, and in fine work as little as can be secured. All spaces should be completely filled. In coursed masonry one-fourth or more of all stones should be headers, *i. e.*, should extend from front to back, and the re-

mainder are stretchers, *i. e.*, lie lengthwise in the wall. Common Rubble has about the strength of mortar; coursed and fine work has nearly the strength of the stone itself. Ashlar is usually backed with Rubble, and both should be carried up together, and, as nearly as possible, the whole length of wall should rise together. The top of the wall is protected by its *cope*, which is a "string-course," *i. e.*, a projecting course; and is made of stones long and broad enough to protect the wall from rain, and heavy enough to be displaced with difficulty; they should be of good shape to shed rain. Adjacent stones in the coping, and in engine and in lighthouse foundations, or other places in which great strength is demanded, are secured together by iron "cramps" or "dowels" of metal or stone.

The joints of masonry are finished on the surface by "pointing" with cement, plaster, or fine mortar, to give smoothness of surface and to cause them to shed rain.

In the Measurement of Masonry, stone-work is measured by taking openings less than 3 feet (0.9 metres) wide as solid wall, and adding 18 inches (0.45 metres) for each jamb. Arches are usually taken as if solid from the springing line; corners are measured twice, and pillars are measured by the area of three sides multiplied by the fourth. Foundations and dimension stones are measured by cubic measure; water-tables and base courses in lineal feet, and sills and lintels in superficial feet.

37. **Brickwork** is laid like stone-work, with the line of courses perpendicular to that of pressure. Broken and soft bricks are rejected, and each brick laid should be wetted and cleaned before laying it in place; the joints should be as thin as $\frac{1}{4}$ or $\frac{3}{16}$ inch (0.64 to 0.48 centimetres). About one-fifth as much mortar as brick is generally used. The "English bond," in which entire courses of stretchers and headers are laid at regular intervals as the wall rises, is considered strongest; when laid one course of headers to each two courses of stretchers, the strength is very nearly the same lengthwise and crosswise. "Flemish bond" is laid header and stretcher alternating in each course; it is easier to retain regularity in breaking joints

in this bond, but it lacks strength and is not as neat in appearance as English bond.

Brickwork is measured by the thousand bricks; with average sizes and good work, the following are the number of bricks laid by the superficial foot:

4-inch	(10.16	centimetres)	wall....	7	to sq.	ft.,	75	to square	metre.
9 "	(22.36	"	) "	...14	"		150	"	"
13 "	(33.02	"	) "	...21	"		216	"	"
18 "	(45.72	"	) "	...28	"		300	"	"
22 "	(55.88	"	) "	...35	"		377	"	"

Corners are measured twice; small openings are taken as solid work; arches are measured as solid from the springing line, and pillars are measured on the face.

Masonry will carry safely from 2 to 10 tons per square foot (21,875 to 109,379 kilogrammes per square metre), according to quality; and carefuliy built masses of cut and dressed granite may carry four times the higher figure.

Masonry in damp situations is always laid in hydraulic mortar or cement, and the lower courses of walls and foundations are usually carried below the frost-line. The soil should be carefully drained. Where new masonry abuts upon old work, there is always danger of cracking by the settling of the new work; but every precaution should be taken to secure a good bond between the two portions and to make the joints of the new work thin, and of cementing material of such consistency as will prevent excessive shrinkage.

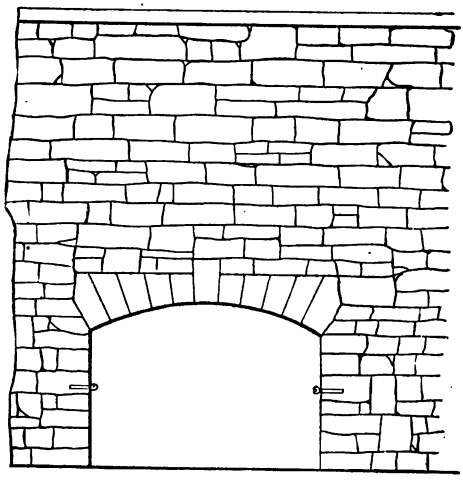
38. The Cost of Masonry cannot be given except on the assumption of a fixed rate of wages. Taking the wages of a laborer at $1.50 per day, and for the mason $2.25, we may reckon as below.

Where wages fluctuate, and, indeed, in all cases, if possible, a careful estimate should be made after ascertaining the conditions actually affecting prices. In the estimate below stones are assumed of moderately large size. Smaller stones cost less to handle, but more for dressing.

Rubble masonry should cost probably one-half these figures if of good quality, and may fall to one-fourth when the stones used are small.

COST OF MASONRY, ASHLAR.

Quarrying $1\frac{1}{3}$ cubic yards.	$3 00	
Dressing 16 sq. ft. face @ 25c.	4 00	
Dressing 48 sq. ft. joint @ $12\frac{1}{2}$c	6 00	
Cost of stone per yard		$13 00
Haulage, variable, say.	1 50	
Mortar	50	
Laying one cubic yard and incidentals	1 50	
Cost of placing		3 50
Contractor's profit, 15 per cent.		2 50
Total cost		$19 00



COURSED RUBBLE WALL.

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CHAPTER II.

TIMBER.

39. "Timber" is that portion of the woody material of trees which is used in carpentry and joinery. Hence the term only applies to the wood of particular kinds of trees, which are therefore designated as "timber-trees." In some districts of the United States, timber cut and dressed is distinctively called "lumber," the term timber being restricted to the standing wood.

The timber-trees are nearly all of those classes known by the botanists as *exogenous*, *i. e.*, those in which growth takes place by the formation of woody fibre on the external surface of the sap-wood, immediately beneath the bark.

Endogenous trees, as those of the palm family, do not furnish timber. Their growth takes place by an internal formation of ligneous fibre, and the wood is not firm and solid enough for the purposes of carpentry.

If the trunks of timber-bearing trees are cut, they are found to be composed of concentric cylindrical layers, whose cross sections form rings, separated from each other, and evidently quite distinct. These layers are formed, one each year, during the period of growth of the tree: They vary in thickness, in density, and in color, according to the rapidity of growth, the length of the season, and other circumstances which may change from year to year.

The outer portion of the trunk is called the "*sap-wood*," and is usually lighter in color, and less strong and dense than the interior portions, or *heart-wood*.

The circulation of the sap through the sap-wood occurs during favorable weather. In winter it is supposed to cease, and this period of checked circulation causes the line of demarkation between successive annual rings.

In midsummer also, in our climate, and in the height of the dry season in tropical climates, the sap flows less freely than either earlier or later in the season. During the month of July, with us, it almost ceases flowing.

The heart-wood is nearly, or quite, impervious to sap, its vessels being closed up, and the wood is dense and hard. It is almost pure woody fibre, is free from sap, and contains almost none of the sugar and the mucilage which are found in sap-wood. It is usually far more durable therefore than the latter. Different kinds of trees, and different individuals of the same species, have different proportions of sap-wood. The slower-growing trees usually contain least.

The complete conversion of sap-wood into heart-wood occupies from one year, as with the softer woods like beech, to twenty or thirty years, and even longer, as with the oak. In the first class, slow growth, and in the second, a comparatively rapid growth, produces the best wood.

Decandolle gives the following as the maximum age of timber-trees, the figures being obtained by counting the annual rings of old trees: Elm, 335 years; cypress, 350; larch, 575; cedar, 800; linden, 1,150; oak, 1,500; and the adansonia, 5,000.

The longevity of various trees has been stated by others to be, in round numbers, as follows: Baobab tree of Senegal, 5,000 years; dragon's-blood tree, 4,000; yew, 3,000; cedar of Lebanon, 3,000; olive, 2,500; oak, 1,600; orange, 1,500; oriental plane, 1,200; cabbage palm, 700; lime, 600; ivy, 600; ash, 400; cocoa-nut palm, 300; pear, 300: apple, 200 years. The Brazil wine-palm attains the age of 150 years, the Scotch fir is matured at about 100 years, and the balm of Gilead at about 50 years.

The length of the life of trees seems largely dependent upon the proportion of heart-wood, and, particularly, upon its durability, decay usually originating and progressing, in growing trees, only in the heart-wood. The sap-wood and bark are peculiarly subject to the attacks of worms and insects. At the period of maturity the heart-wood is of maximum density and uniformity of texture.

40. "Felling" Timber should always, if possible, be practised at the period of maturity; if earlier, the wood will not have acquired its greatest strength and density, and will contain too great a proportion of sap-wood; if later, the wood will have become weakened by incipient decay.

The oak is said to reach maturity when about 100 years of age, and it should not be felled at less than 60.

Pine timber should be cut at from 70 to 100 years of age, and ash and elm at from 50 to 100.

The season of the year best adapted for felling timber is either midwinter or midsummer. The months of July and August are often selected, as at those seasons the sound trees remain green, while the unsound trees are then turning yellow. Healthy trees then have tops in full foliage, and the bark is uniform in color, while unsound trees are irregularly covered with leaves of varying color, having a rougher, and often a loosened, bark, and decaying limbs.

The cut should be made low, and the opposite incisions should be so made, especially with oak, as to enable the trunk to be cut clear of the stump while falling; otherwise the trunk may be split. The trunk should be immediately stripped of its bark, and, when heart-wood only is wanted, the sap-wood removed as soon as possible. The bark is often removed from trees in spring, and the felling deferred until autumn or winter. This is probably the best course to pursue, usually.

Handspikes and similar "uses" should be cut from young straight trees, and near the butt.

41. Seasoning Timber is simply driving out the sap from its pores by either natural or artificial means. This should always be done as gradually as possible, otherwise the timber is liable to crack or "check," from irregular drying.

Natural or air seasoning gives the best results. The timber should in all cases be squared as soon as cut, and all large logs should be halved, or even quartered. It is then piled in the seasoning yard in such a manner as to be protected as far as possible from the sun and rain. It should be placed where the air may circulate freely on all sides, not only of the pile, but of each log; bad ventilation is sure to cause rot. After

remaining thus for some months, the logs may be cut into smaller joists, if needed in such form, or into planks and boards, and again piled for further seasoning. For heavy work, two years, and for lighter work, four years, is sufficient time for seasoning boards; but timber is rarely overseasoned.

The loss of moisture in the first year of seasoning may be taken usually as about twenty per cent. When piled for seasoning in air, the lower sticks should be placed on supports one to two feet high, to keep them from contact with the damp earth. At least an inch should separate adjacent pieces. The timber should be repiled often enough to secure the detection and removal of unsound pieces.

Water seasoning is accomplished by immersion in water for a long time. It is a slow and imperfect method, but for timber to be used in water, or in damp situations, it answers well. The sap, in this case, is removed by solution.

In salt water there is usually some danger that the wood may be attacked by the ship-worm, *Teredo navalis*, or by the *Limnoria terebrans*, both of which destroy timber very rapidly. It should therefore be carefully watched. Two or three weeks water seasoning is sometimes found to be a good preparation for air seasoning, by dissolving out the more soluble salts contained in the wood.

Steaming timber is resorted to where it becomes necessary to soften wood, in large pieces, for the purpose of bending it, as in ship-building. An hour to each inch of thickness is the period of time allowed. This process sometimes impairs the strength; but it is also a seasoning process, and preserves from decay as well as from injury by warping or cracking.

Hot-air seasoning is resorted to where it becomes necessary to season wood rapidly. The timber is piled in large chambers or ovens. The sap is expelled by a current of hot air, having a temperature of from 100° Fahr. (38° Cent.), with large logs of hard wood, to 250° to 300° Fahr. (121° to 149° Cent.), with thin boards of the softer kinds, the wood losing, in the latter class of materials, about thirty per cent. of its weight.

The time required may be stated to be generally one week

for each inch (2.54 centimetres) of least thickness, to insure good work.

In seasoning the birch sticks, one inch or one and a quarter inch (3.2 centimetres) square, sixty hours are allowed.

The fuel used amounts to about ten per cent. of the weight of seasoned wood.

Seasoning by passing the smoke-laden products of combustion from the furnace, directly through the pile of timber, has been found not only a good method of seasoning, but also to have an important and useful preservative effect.

Seasoning by boiling in oil is resorted to for some purposes, as the preparation of hickory for use in making teeth of mortice gears. If carelessly done, the wood may be seriously injured by the charring of its fibre in the overheated liquid; but if the temperature is carefully kept at, or somewhat under, 250° Fahr., the result will be most satisfactory.

The wood should be seasoned in blocks roughed out to nearly the finishing size, and they become not only well and uniformly seasoned, but, as shown by the experiments of Mr. G. H. Corliss, considerably strengthened.

If well done, seasoning usually increases the strength of timber, but the amount of this increase is very variable. Pine gains about ten per cent., elm from ten to fifteen, oak from five to twenty-five, and ash and beech often gain forty per cent. or more.

The amount of water contained in green timber varies from twenty-five or thirty per cent., in willow and ash, to thirty-five per cent. in oak, and forty per cent. in pine.

Large beams are best built up of small pieces, in order to secure thorough seasoning, and to avoid risk of decay.

42. Shrinkage always occurs to a greater or less extent, in consequence of the expulsion of moisture while seasoning; and some woods not only shrink, but warp badly, while others are seriously injured by the occurrence of "seasoning cracks."

The shrinkage of timber is not usually very noticeable in the direction of its length; but transverse shrinkage often occurs to a marked degree. In soft timber, as birch, it amounts to about eight per cent.

The tree consists of a bundle of capillary tubes, cohering laterally, the sap-wood, when green, filled with sap, and having the heart-wood moist, but choked with resinous matter.

These fibrous bundles, or the *vascular tissue*, are bound together by a *cellular tissue*, the membrane which constitutes the medullary rays, which latter form, in many woods, as in oak, well-marked dividing planes and lines of weakness; they consequently determine the surfaces along which season cracks may be developed while shrinking. The inner portions of the tree, the heart-wood, being denser and less fully saturated with moisture than the external or sap-wood, shrinks less, and thus it happens that all planks, composed of portions of both kinds of wood, or of different qualities of the same kind, are certain to be warped or otherwise distorted while seasoning.

Usually a log is cut into planks, when green, by gang or circular saws, and these planks, originally of the shape seen in Fig. 17, are likely, when seasoned, to take the shapes seen in Fig. 18.

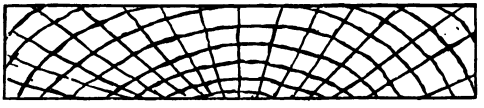

FIG. 17.

The shrinkage warps the outer planks and distorts the middle one, by reducing its thickness to a greater extent at the edges than in the middle. The simple inspection of the position of the medullary rays and annual rings in a piece of green wood will enable any one to determine from what part of the trunk it has come, and to predict its change of form while seasoning.

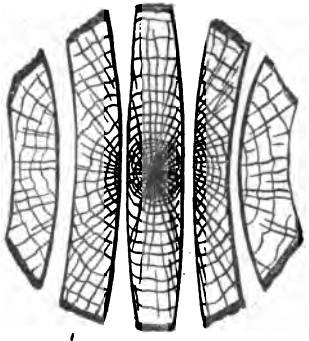

FIG. 18.

43. **Nomenclature.**—The term *timber* is seldom applied, in the trade, to logs cut from trees less than eight inches (20.3 centimetres) in diameter. Smaller sizes are called *joists*.

Before felling, it is called *standing timber*; when first cut,

it is called *rough timber;* and after it has been sawn, it is called *converted timber;* and is also known as *sided timber*, joists, plank, or board, according to dimensions.

Wood is either *soft* or *hard wood.*

The first class includes the wood of all coniferous trees, as the pines, and of a few others, as for example white birch.

The second class includes the wood of all other timber-producing trees.

The soft woods generally contain turpentine and pitch, and are usually of rapid growth, straight-grained, of slight density, quite uniform in texture, and comparatively free from knots. They have but little lateral adhesion of fibre, and are easily worked.

The hard woods are denser, heavier, and stronger, less easily sawn, split, or cut, and are more liable to warp and to crack than are the soft woods. They usually excel in durability, and in some cases are very tough and elastic.

44. **Characteristics of Good Timber.**—Good timber has the following characteristics: The heaviest is usually the strongest and most durable. That which has least sap or resin is the best.

The freshly cut surfaces are firm and smooth, and the shavings are translucent, and should nowhere appear chalky or roughened, that being the first indication of decay.

The annual rings should be closely packed, and the cellular tissue of the medullary rays should be hard and dense.

The tissues should cohere firmly, and when sawn there should be no wool-like fibre clogging the saw-teeth.

In general, the darker the color, the stronger and more durable the wood.

Inspection of Timber.—Timber should be inspected in dry weather, when the defects are not concealed by moisture.

The color should be bright and uniform, slowly changing from sap-wood to heart-wood, and free from the white spots which indicate incipient decay. Dry-rot is indicated by yellow stains.

Usually sap-wood should be thrown out, except in a few cases, as in ash, lancewood, and hickory, where it is sometimes

even better than heart-wood. The use of the centre heart-wood of mature trees is also usually avoided as being liable to early decay.

Brash-wood, which is old and brittle in consequence of age, is rejected, as is also knotty timber, twisted wood, and the timber which has been felled after having died from natural causes, like belted timber.

The preparation and inspection of small pieces is best illustrated by the regulation system adopted in the national armories with reference to securing good material for musket and rifle stocks and butts.

The wood used is the best American or Italian walnut. After seasoning about three years in the rough, or, if artificially dried, after being exposed to a temperature of 60° F. (15°.5 C.), slowly raised to 90° F. (32° C.), and held at the latter temperature six to eight weeks, the pieces are handed over to the inspector.

If defective in either of the following respects, they are rejected: *

1. Under size.
2. Misshapen.
3. Galls.†
4. Shakes.
5. Rind galls.‡
6. Discolored wood.
7. Knots or bines.
8. Crooked or cross-grain.
9. Decay.
10. Worm-holes.

They are also examined to determine whether they have been soaked in salt water, the presence of which produces rapid corrosion of the metal of barrel, lock, and mountings. The test is made by dipping a shaving into a solution of nitrate of silver; the presence of salt is shown by the formation of a white precipitate of silver chloride.

45. **Influence of Climate and Soil.**—These greatly affect the value of timber. Generally the strongest varieties of wood come from tropical climates, but the best examples of any one variety are usually from the colder portion of the range of country in which it abounds.

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* Ordnance Notes, No. 197.

† Produced by insects depositing their eggs in the tree.

‡ Due to surface injuries to the sapling.

Timber of slow growth, in situations protected from violent winds, cut at the right time of year, and properly seasoned, is free from "cracks" and "shakes," or "checks."

Cup-shakes are produced by the wrenching of the tree by winds, and are cracks separating one layer from another. Timber thus injured is sometimes called "*rolled* timber."

Longitudinal cracks are produced by heavy winds also, and by too rapid seasoning; in the latter case they are called *seasoning cracks*, in the former, *wind-shakes* or *cracks*.

Frost, in cold climates, sometimes produces this kind of injury.

Cup-shakes often injure oak, hard pine, mahogany, and elm, but they do not as generally affect soft pine.

"*Heart-shakes*," which are cracks crossing the heart-wood, sometimes single and sometimes grouped, making a "*star-shake*," affect all kinds of timber.

46. Decay of Timber.—Timber decays in two quite different ways, the causes of decay being, however, the same in both cases, namely, fermentation and putrefaction.

Dryness is the best preventive of decay of timber used in general construction, and wood kept dry has been found to last several centuries. Still, it finally becomes brittle and weakened, and may ultimately give way under a light load.

Water seems to act as a preservative, and some kinds of timber constantly immersed in water *not in motion* may endure for an indefinite period. The first effect of water is to dissolve out soluble matter, leaving the woody fibre or *lignine* uninjured, except perhaps very slightly by oxygen in solution in the water. This oxygen being exhausted however, no further action occurs unless a fresh supply of air-laden water displaces that originally in contact with the wood.

Alternation of moisture and dryness induces rapid decay. This takes place partly by solution and removal of a portion of the substance at each moistening, and partly by the action of oxygen dissolved in the water, a fresh supply of dissolved oxygen being furnished at each repetition of the moistening.

Continued dampness in a warm atmosphere is most favorable to fermentation, and consequently to rapid decay. This

putrefaction of woody fibre is known as "rot" among those who use timber.

The products of this decomposition are, as in cases of rapid combustion of wood, carbonic acid and water. The presence of water is necessary, as well as that of air, to the rapid progress of this chemical change, although the oxygen, which is essential, may sometimes be obtained from some source other than the atmosphere.

Sap-wood is more perishable than heart-wood, in consequence of the presence of saccharine and other matters having a peculiar tendency to fermentation. It is in consequence of this fact that the complete removal of the sap by seasoning is necessary.

Lime, by its tendency to abstract carbon, which, uniting with oxygen, combines with lime to form the carbonate, hastens the rotting of wood wherever it is damp. Dry lime and the carbonate do not have this effect.

47. "Wet-Rot" and "Dry-Rot" are the two forms in which the decay of timber exhibits itself.

Wet-rot occurs in any portion of the wood, if damp, and attacks the heart-wood of standing timber.

Dry-rot is usually produced by the want of circulation of air, and by high temperature, where the timber has not been well seasoned.

The most rapidly growing trees are most subject to decay, and those growing in sheltered localities are more liable to rot than those in exposed situations.

Of soft timbers, that containing most turpentine is least liable to rot.

Woodwork embedded in damp plaster, and unseasoned timber covered with a coating of paint, are subject to dry-rot, and are apt to decay early, in consequence of the confinement of air and moisture within their pores. Any thing which absorbs moisture and confines it in contact with wood is likely to accelerate decay.

48. Marine Animals frequently attack timber immersed in salt water, as the bottom of vessels, piles, etc.

The *Teredo navalis*, commonly known as the ship-worm,

converts the wood which it enters into a perfect honeycomb. It enters the wood when very small, and there increases in size, and enlarges its chambers correspondingly, until it sometimes makes borings an inch (2.54 centimetres) in diameter, and several feet long. Soft woods are very rapidly destroyed by it, and the hardest woods are not safe against its attacks.

The *Limnoria terebrans* is a smaller creature than the Teredo, shaped somewhat like a wood louse, and is rather more than an eighth of an inch (.3 centimetres) long. It is very destructive, cutting out the wood along the annual rings.

There are several other marine animals which attack timber, and it is usually necessary to protect it, when immersed in salt water, by sheathing with copper, as ships are protected, or otherwise covering it with a coating impenetrable by these animals.

Some kinds of timber are much less liable to this kind of injury than others. The East Indian teak is said never to be attacked by either of these creatures, and live oak is comparatively little injured by them.

49. **The Varieties of Timber** used in carpentry, joinery, and pattern-making are very numerous; and the forests of our own country yield immense quantities of some of the most useful kinds.

They are divided into two great classes:

Pine Woods, or the Coniferæ, are distinguished by their spine or needle-like leaves and resinous turpentine-yielding sap.

Leaf-wood comprehends all other timber-trees, and bears leaves of the ordinary broad, thin, and irregular shapes; its sap is destitute of turpentine.

The latter woods are usually best where strength, durability, and hardness are demanded; the former excel in lightness, elasticity, and flexibility.

The Leaf-woods are divided into two classes: (1) Those which have their medullary rays broad and well marked; (2) woods in which those rays are indistinct.

These classes include each two sub-classes: (*a*) Those in which the annual rings are distinctly marked, as in the oak of

the first, and in the ash of the second class; (*b*) those in which the rings are obscure, as in beech of the first, and walnut and mahogany of the second class.

50. White Pine (*Pinus strobus*) is a native of North America, and takes its name from the color of its wood. It grows in all kinds of soil. The best timber is found in cool, damp situations in the forests of the Northern United States and Canada, between the forty-third and forty-seventh parallels of north latitude. It rarely flourishes well as far south as Virginia. It grows to a great size, reaching a height of upwards of 200 feet (61 metres), with a diameter of 10 feet (3.05 metres) at the height of a man's shoulder from the ground. It is the tallest tree in our forests. It sometimes reaches the age of 350 years. Single logs have been cut 36 inches (91 centimetres) square and 60 feet (18.3 metres) long. Its wood is yellowish-white in color, light in weight, rather soft, free from knots, straight grained, and is very easily cut. It is durable only in dry air. It contains very little resin. Its leaves are very slender, and are pale green in color; its cones are early cylindrical, and four or five inches (10 to 12.7 centimetres) long.

Its specific gravity is about 0.70 green, and 0.50 seasoned, its weight being quoted at 44 and 30 pounds per cubic foot respectively (705 and 480 kilogrammes per cubic metre).

It is used for light carpenters' and joiners' work, and is remarkably well adapted to pattern-makers' use. It has been employed to a considerable extent in building wooden bridges.

It is not a very strong wood, and swells or shrinks seriously when the hygrometric state of the atmosphere changes considerably. For many purposes its softness is a serious objection.

51. The Canadian Red Pine (*Pinus resinosa*) is found growing on the poorer soils of the northern portion of the United States, and in Canada, reaching a height of 80 feet (24.4 metres), and attaining a diameter of 2 feet (.6 metres). It is wrongly called, in various localities, "Norway Pine" and "Yellow Pine."

The leaves are in pairs, and five or six inches long (12 to 15 centimetres).

The wood is fine-grained and white, with a reddish tinge, somewhat soft, but quite strong and durable. It is so soft and flexible, and so readily worked, as to be a favorite timber for light work. It makes excellent planking and spars for ships.

FIG. 19.—PINE.

52. The American Yellow Pine, "*Spruce Pine*," or *Short-leaved Pine* (*Pinus mitis, Pinus variabilis*), is found throughout the country, in dry sandy soils, from New England to Georgia.

It attains a height of 60 feet (18.3 metres), and a diameter of 18 inches (45.6 centimetres). The trunk is straight and slender. Its cones are small, its leaves are in groups of threes, and from 3 to 5 inches (7½ to 12½ centimetres) long.

The heart-wood is fine-grained, moderately resinous, strong and durable. The sap-wood is poor in quality, and decays rapidly.

It is much used in carpentry, and for framing and flooring, and in ship-building; it is also used for the masts and yards of large vessels.

53. The Southern Pine, "*Long-leaved Pine*" (*Pinus australis, Pinus palustris*), is distributed along the Atlantic coast from Maryland southward, on sandy, light soil. It is probably the most generally useful of our woods, and immense quantities are brought into market.

Its name is very commonly confused with that of the *pitch pine*, and both kinds of wood are known in the Eastern States as *hard pine*.

Both the yellow pine and the pitch pine are extensively used, by Atlantic ship-builders, for planking, beams, keelsons, etc., but seldom for any part of the frames.

The yellow pine sometimes attains a height of 150 feet

(45.7 metres), and a diameter of 4 feet (12.1 metres); but the pitch pine seldom exceeds two-thirds this size. The former is principally obtained from the States of Virginia, North Carolina, and Georgia, while the latter is abundant in all the Atlantic States south of Chesapeake Bay. The yellow pine required for navy-yard use is described as long-leaved, fine-grained, Southern yellow pine.

Its leaves are rigid, and 8 to 11 inches (20.3 to 27.9 centimetres) long; they are dark green in color. The cones are 6 to 8 inches (15.2 to 20.3 centimetres) long.

It has but little sap-wood, and the heart-wood is of very uniform quality, its resinous matter being very regularly distributed. Its grain is fine and close, and it has greater strength, durability, and hardness than any other species of pine.

Though not so tough and elastic as white oak, the yellow pine, especially that from Georgia, successfully rivals it in stiffness. If a beam of each kind of timber, equal in dimensions, be supported at the ends, the oak beam will depart most from its "mould," but will break under about the same load.

In dry situations the pine is extremely durable, and where the properties of lightness and solidity are required in combination, it is to be preferred to oak.

Experiments upon the shrinkage of various woods, by Mr. James Jarvis, at the U. S. Navy-yard, Norfolk, Va., indicate that yellow pine should be cut in summer.

54. **The Pitch Pine** (*Pinus rigida*), is common throughout our country, frequenting sandy or lean rocky soils. The best qualities come from Florida. It is distinguished by peculiarly rough, dark bark, and by the abundance of its resin. Its leaves are in groups of three, 3 to 5 inches long (7.6 to 12.7 centimetres).

The wood is close-grained, heavy, free from knots, elastic, quite strong, and very durable. It is more dense than yellow pine; which latter has the preference for all work to be covered by paint. Pitch pine is very stiff, and moderately fine-grained.

In using yellow and pitch pines, the best timber for strength and durability is not necessarily that of the greatest density. The timber of greatest weight is often heavy simply because of the presence of a surplus of turpentine in its vessels.

55. The Foreign Northern Pine, *Yellow Fir, Red Fir,* or *Scotch Fir* (*Pinus sylvestris*), is found in all parts of Northern Europe, including Great Britain, where the forests are largely composed of it.

FIG. 20.—RED FIR.

It is very much used in Europe, and is obtained in Great Britain, Norway, Sweden, and Russia, and from the Prussian ports of Memel, Dantzic, and Stettin. The logs are sometimes as large as 80 feet (24.4 metres) long and 26 inches (66 centimetres) square. The yellow deals from Christiania are most durable, but a large waste occurs in working them, in consequence of their large proportion of sap-wood.

The durability of the better quality of this timber is considered by some engineers to equal that of oak.

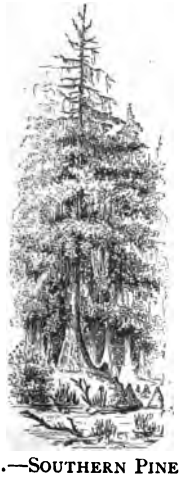

FIG. 21.—SOUTHERN PINE TREE.

Like the American white pine, it is excellently adapted for framing, and for light carpenters', joiners', and pattern-makers' work.

In Great Britain, the American white pine is, however, considerably used instead of the native fir.

56. The Cypress (*Cupressus disticha, Taxodium distichum*), or deciduous cypress, is a tree of the pine family, having a trunk sometimes 10 or even 12 feet (3.05 to 3.66 metres) in diameter, and attaining the height of from 120 to 130 feet (36.58 to 39.63 metres). Its foliage is a delicate light green in color, the leaves linear.

awl-shaped, and spreading, and borne upwards on slender branchlets.

The tree is found from the Hudson to the Gulf of Mexico, and flourishes best in southern latitudes, attaining greatest size in the swamps of the South, where the soil is a deep, rich, black, and wet mud. The roots of old trees are often partly exposed and singularly contorted. The lower portion of the trunk is frequently hollow.

The wood is considered excellent for many purposes. It is soft, light, straight-grained, and easily worked, and is imperishable where covered with water. It is extensively used in those localities throughout which it is most abundantly distributed, and sometimes as a substitute for oak.

57. **The Qualities of Pine Timber** are readily determined by a practised observer. Good wood has a close grain, and its slow growth should be evidenced by the thinness of the annual rings, which should not exceed a tenth of an inch (.75 centimetre).

The trunk, and consequently its rings, should be symmetrical.

The best timber is charged with resin, and this preserves it from decay, and gives it strength and elasticity; its presence is indicated by strong odor. The color of the wood should be a clear tint of yellow and red, alternating, and the texture should be very uniform, as well as the colors.

The working of the timber gives a reliable indication of its quality. It should offer considerable resistance to splitting along the grain; it should be strong and free from wooliness, and the cut of the saw and of the plane or chisel should leave smooth surfaces. The shavings and chips should be strong and elastic, and the former capable of being twisted about the fingers without breaking.

58. **The Firs** are closely related to the pines, and furnish a large quantity of excellent timber to the markets of Europe and of America.

59. **The White Fir,** *Norway Spruce*, or *White Deal* (*Abies excelsa*), grows in the mountainous portions of Northern Europe. It is tall and straight, excelling all its congeners in

these respects. It reaches the height of 100 feet (30.5 metres) and attains a diameter of 3 feet (.91 metre). Its cones are cylindrical, 5 to 7 inches long (12.7 to 17.7 centimetres). It is used in Great Britain largely, being imported principally from Christiania and other Northern European ports. It is now frequently met with in North America.

This wood adheres well to glue, and is quite durable and strong, but it is not equal to the best varieties of pine.

It takes a fine polish, and is largely used for flooring and panelling, and is well adapted for spar-making.

Burgundy pitch is obtained from this tree.

THE AMERICAN WHITE SPRUCE FIR (*Abies alba*) is so called from the color of its bark and leaves. It is found in the rougher portions of the North American forest-covered country, and grows to a height of 50 feet (15.24 metres). Its cones are but 1 or 2 inches long (2.5 or 5.2 centimetres). It is quite similar in quality to the Norway spruce fir, and excels it in toughness. It is rather less durable and is less dense; it is also more liable to warp in seasoning.

FIG. 22.—"SPRUCE."

60. The Black Spruce Fir (*Abies nigra*) is found in the same range of climate as the white spruce, but it prefers a more level country. It forms extensive forests in Lower Canada. It attains a height of 70 feet (20.73 metres), and occasionally even 100 (30.5 metres), and reaches a diameter of 2 feet (.61

metre). The leaves are dark and stiff, four-sided, and needle-shaped. The cones are 1 or 1½ inches (2.5 or 3.8 centimetres) long. The wood resembles that of the white spruce, and is generally more highly valued. Its strength, durability, lightness, and elasticity form a combination of good qualities that makes it, for some purposes, the best wood in our markets.

61. The Red Spruce Fir (*Abies rubra*), or *Newfoundland Red Pine*, as it is also called, grows in the north-east portions of North America, and affords an excellent material, perhaps hardly excelled by the black spruce. Its size is about the same as that of the black variety. It is especially prized for yards and spars of ships. Fir timber has a specific gravity of from 0.6 to 0.8, weighing from 36 pounds dry to 48 pounds green per cubic foot (577 to 769 kilogrammes per cubic metre).

62. The Larches (*Larix Europæa, Larix Americana*) are natives respectively of Europe and America. Their wood is hard and strong. Their leaves are very slender, light green in color, and short. Their cones are about one inch long. This wood has not the lightness nor the elasticity of white pine, but is tougher and more close-grained, and is far less inflammable than are woods generally.

FIG 23.—LARCH.

Larch is hardly excelled by any other wood in durability. The European larch was celebrated for this quality from a very early period. Even when exposed to alternately wet and dry weather, it is quite durable, lasting sometimes thirty years

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under most unfavorable conditions. The American variety of larch, known as Hackmatack, is highly prized by our shipbuilders. It attains a height of 100 feet (30.5 metres), and a diameter of 3 feet (.91 metre). It is found from Virginia to Canada.

63. The Linden, *Basswood, Lime* (*Tilia Americana, T. Europæa*, etc.), is found throughout a wide range of climate in both the United States and Europe, and has many varieties. The useful varieties are trees of moderate size, bearing large, smooth, heart-shaped leaves alternating on the stem, and having fragrant flowers which are favorites with the bees. The foliage is dense, and the tree is an excellent shade tree, but very subject to the attacks of insects.

FIG. 24.—BASSWOOD.

The wood is yellowish-white, soft, and light, but moderately close-grained and tough. It is used largely for furniture, coarse carvers' work, and to some extent in carpentry. The inner bark, or "bast," is used for making coarse matting, baskets, etc.

64. The Cedars and Junipers are woods of less general application than the pines; but have, nevertheless, great value in construction.

THE WHITE CEDAR (*Cupressus thyoides*) is found on the Atlantic coast of the United States from New York to Georgia, wherever the soil is wet. It is the principal inhabitant of the interior swamps of New Jersey and of Virginia, and trunks are often found of large size, sound and merchantable, lying far below the surface, embedded in mud and peat.

It grows to a height of 80 feet (24.4 metres), and to 3 feet (.91 metre) in diameter, with a straight stem and branches up to within 30 feet (9.1 metres) of the top.

Its resin is yellow, slightly odorous, and small in quantity. The cones are small, greenish in color, becoming bluish at the end of the season.

The wood is odorous, soft, fine-grained, light, and easy-working, taking a red tint, and often a decided color, when seasoned.

It resists the weather remarkably well, and is, therefore, used very extensively for shingles.

The wood makes the best of railroad ties for light traffic, but is too soft for general use; it makes excellent fencing and telegraph poles, and domestic utensils are often made of this wood. It is cut at all seasons, but best when the sap flows most slowly.

THE VIRGINIA "RED CEDAR" (*Juniperus Virginiana*) is found in nearly all parts of the United States and Canada. It is, when fully grown, from 30 to 50 feet (9.1 to 15.2 metres) high, and sometimes 12 inches (.3 metre) in diameter. It is found on dry, sterile, rough country.

The wood is light in weight, weighing 32 pounds green, and 28 pounds seasoned, per cubic foot (512 and 448 kilogrammes per cubic metre). The color of the heart-wood is red, while that of the sap-wood is white. It is brittle, compact, and durable, and has a strong characteristic odor and a bitter taste, which preserves it from the attack of insects.

FIG. 25.—CEDAR.

It is especially valuable for drawers, chests, boxes, and some kinds of furniture. When well-seasoned it makes excellent rulers and T-squares. It is extensively used for covering lead-pencils, and is sometimes called *Pencil Cedar*.

THE BERMUDA JUNIPER (*Juniperus Bermudiana*), or *Bermuda Cedar*, is a native of the West Indies. It is harder and heavier than the pencil cedar, and has a similar odor and appearance. It is very durable when well seasoned and free from sap-wood, and has been considerably used by ship-builders for planking.

These cedars, or more properly junipers, are largely used for drawers, wardrobes, and church furniture. The California "Cedars" grow to enormous size.

65. Tar, Pitch, and Turpentine are obtained from the more resinous trees of the pine family.

Tar is obtained by a rude distillation of the heart-wood of pine. It is viscous and semifluid at ordinary temperature, solid when cold, and quite liquid when heated. It is brownish-red in color, becoming black with age or by the presence of impurities, or by overheating when made.

It is used for preserving cordage, and the oakum which is

FIG. 26.—TAPPING THE PINE.

used in calking the seams of vessels, and as a binding material in artificial fuels, and in some kinds of cement.

Pitch is made by boiling tar until its consistency is considerably increased. It is hard at ordinary or low temperatures, but is softened by the heat of the hand. It is used as a cementing and preservative material. *Rosin*, or *colophony*, is a pitch obtained by distilling turpentine. The best is lightest in color.

Turpentine is the sap of the pine. The tree is tapped annually when the sap is flowing most freely. White, or "virgin" turpentine, is obtained from the tree the first season; during succeeding seasons the product becomes gradually darker, and is known as "yellow-dip." Trees are tapped twelve or fifteen years in succession. A large part of the turpentine in the market comes from North Carolina.

The following description of the process of distillation may explain further: *

A fifteen-barrel copper still, the barrel weighing 220 lbs. (100 kilogrammes), is charged early in the morning. Heat is applied until the mass attains a uniform temperature of from 212° to 316° Fahr. (100° to 158° Cent.). This is continued until the water contained in the crude turpentine as it comes from the forest has been driven off.

The first product distilled over contains pyroligneous acid, formic acid, ether, and methylic alcohol, with water. This is known as *low-wine*.

All the water having been distilled off, a small stream of cold water is now let in, so that the heat is kept at or below 316° Fahr. (158° Cent.), the boiling point of oil of turpentine. The oil of turpentine and water now come over, and the mixture is caught in a wooden tub. This tub is constructed as follows:

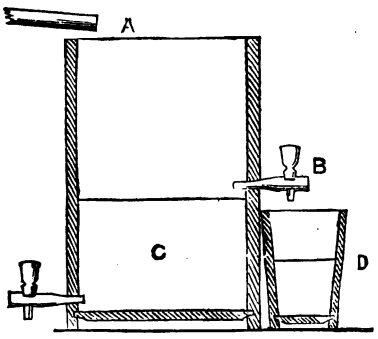

FIG. 27.—SEPARATOR.

The distillate is caught at *A* from the still, and separates into water and oil. At *B*

* *Scientific American.*

there is an overflow spout, which discharges into the tub *D*. The water is kept low enough in the lower part of the tub to prevent its overflowing through the cock *B* into the receptacle *D*. From this receptacle it is put into oak casks, well secured with iron hoops, and thoroughly glued inside.

The distiller tests the quality of the flow from time to time in a proof glass. The distillation is continued until the proportion of fluid coming over is nine of water to one of oil of turpentine. At this stage the heat is withdrawn, the still-cap is taken off, and the hot rosin, which remains in a fluid state in the still, is drawn off by a valve or cock at the side of the still near the bottom.

The yield of oil of turpentine from "virgin dip" is about 6 gallons (27 litres) to the barrel.

The yield of oil of turpentine from "yellow dip" is about 4 gallons (18 litres) to the barrel.

FIG. 28.—TURPENTINE STILL.

Venice turpentine is that obtained from the larch. It is sometimes imitated by mixing rosin and spirits of turpentine.

Spirits of turpentine is the essential oil of turpentine, and is obtained by distillation.

66. The Oaks form a most valuable class of timber-trees, and a large number of species are known and used. Of more than sixty species known to botanists, over forty are natives of North America, and several produce very excellent timber.

The best kinds of oaks are, if properly prepared for use, the hardest and most durable of woods. Kept either under water or perfectly dry, oak has been known to last several centuries. It is strong, tough, and moderately stiff. There are, however, varieties of oak which yield inferior timber, and trees of the same species may yield either superior or inferior timber, according to the nature of the soil and the climate in

FIG. 29.—OAKS.

which they have grown. The texture is alternately dense and porous.

The wood has a peculiar odor and taste, the latter being due to the presence of gallic acid, which, by contact with

iron, produces an ink which blackens the wood and corrodes the metal.

The oaks grow on a great variety of soil, preferring a clayey subsoil overlaid with rich loam.

67. The Live Oak (*Quercus virens*) is one of the best known ship-timber trees. It is evergreen, and grows on the sea-coast from Maryland to the Gulf of Mexico and the Mississippi, and is now so scarce and so valuable that the government has reserved all of the Florida live-oak forests for naval purposes.

The tree grows to a height of 60 feet (18.3 metres), and to a diameter of 4 feet (1.22 metres), but is usually 40 or 45 feet (12 to 13.7 metres) high, and 12 to 18 inches (30.5 to 46 centimetres) in diameter. The sap-wood is whitish in color. It is free from the glutinous matter which fills the capillary vessels of the denser heart-wood. Unlike other varieties of oak in our country, it is free from acid.

This timber is used almost exclusively for the purposes of ship-building, and is the most costly ship timber in the market. It is heavy, compact, fine-grained, yellowish in color, and is the strongest and most durable of all American woods.*

It is not well adapted to the reception of spike fastenings, as the grain refuses to receive the point in the cutting direction, and permits splitting of the wood. There is no difficulty, however, in fastening with bolts and treenails.

Live oak, if exposed long in the open air, in the rays of the sun, or to winter winds, will check badly. It does not require many months of air seasoning, however, to fit it for its ordinary uses.

68. The White Oak (*Quercus alba*) is a more common and a very valuable variety of oak. It is especially valuable for ship-building, for which its trunk furnishes the heavier beams, and its large roots and branches yield the compass timber.

* The Author possesses a live-oak cane, taken in 1865 from the *keel* of the frigate *United States*, a naval vessel built very early in the present century. It is as perfectly sound, apparently, as when first cut.

It is used for water-wheel shafts and steps, and other millwrights' works, and for artillery carriages. The wood from the roots makes beautiful furniture. The cost and the difficulties of working it preclude its extensive use. The bark is rich in tannin, and is of great value for tanning leather.

FIG. 30.—WHITE OAK.

This tree is found from Canada to the Carolinas, and is most abundant in the Middle States, forming large forests west of the Alleghany range of mountains. It reaches a height of 80 feet (24.3 metres) and more, and its trunk is sometimes 6 or 7 feet (1.8 or 2.1 metres) in diameter. It is one of the few trees which retain any of their leaves throughout the winter. The leaf is deeply indented, long and narrow. Its bark is of a light grayish-white color, giving it its name; the wood is light straw-colored, with a tinge of red, and is very tough, strong, durable, elastic, and pliable, with strong lateral cohesion. It is very liable to shrink, warp, and crack in seasoning, and is therefore of little value for boards. The shrinkage amounts to about one thirty-second.

The wood of trees 60 to 100 years of age is much tougher, particularly on high lands, than that of older trees. No certain data exist for comparing the properties of white oak grown in various districts, but it is generally supposed that the best timber for durability is that grown near the Atlantic seaboard, or along the borders of the great lakes. Generally the strongest timber is grown on wet lands. The experiments of Jarvis prove, first, that there is ten per cent. in one year, and five per cent. in four years, more shrinkage in

weight of the squared timber which is cut in the warm season, than in that cut during the cold season; secondly, that in the case of round logs, in bark, there is eight per cent. in one year, and seventeen per cent. in four years, more loss by evaporation if cut in the summer season.

It has a specific gravity of from .7 to 1.1, weighing from 44 pounds, dry, to 70 pounds, green, per cubic foot (705 to 1,121 kilogrammes per cubic metre).

69. The Post Oak (*Quercus obtusiloba*), or *Iron Oak*, is common in Maryland, and east of the Alleghanies in Virginia, where it is also called the Box White Oak. It is occasionally found as far north as New York and New England.

It produces excellent timber, but seldom exceeds a foot or 15 inches in diameter, and a height of 50 feet (15.24 metres). The wood is of a yellowish hue, close-grained, and is often superior to the white oak in durability and strength. It is also finer grained. It is a most excellent wood for constructive purposes where of sufficient size, and is used for knees in ship-building, and for staves.

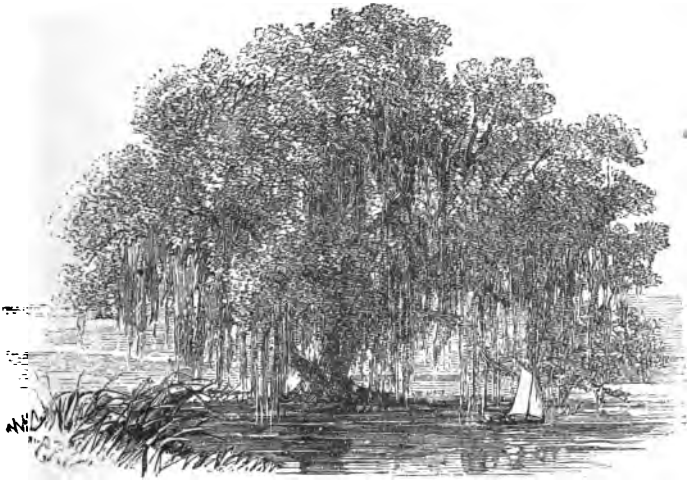

FIG. 31.—SWAMP OAK.

The Swamp Post Oak is found in the Carolinas and in Georgia, in swampy and often inaccessible districts. It is

larger than the preceding species, and is an excellent timber-tree.

70. **The Red Oak** (*Quercus rubra*) is a Canadian tree, which grows with considerably greater rapidity than either of the preceding. It is usually smaller, but attains a height of 100 feet (30.5 metres). Its leaves change to a red color before falling, in autumn, and this fact gives the tree its name.

The wood is easy to work, light and spongy, and lacks the durability of the better kinds. It is coarse-grained, and is only used to any considerable extent for staves.

71. **The Rock Chestnut Oak** (*Quercus primus monticola*) grows in the Middle States, and as far north as New England. It is most plentiful among the Alleghanies, and is more durable, and is, in other respects, nearly as valuable as the white oak, but its scarcity prevents its equally extensive use.

72. **The Chestnut White Oak** (*Quercus primus*) is found in the Southern Atlantic States.

It produces a strong and durable wood, although not equal to the white or the post oak. It is used to some extent in wheelwrights' work, and is considered nearly equal to white oak for ships' frames.

73. **The British Oak** (*Quercus pedunculata*) is found all over Europe, and is most common in England and France. It grows to a height of from 70 to 100 feet (20.7 to 30.5 metres), and attains a diameter of 6 feet (1.8 metres).

The wood has a light brown or reddish tinge, with numerous large medullary rays. It is tough and strong, quite hard, straight-grained, free from knots, splitting freely, and is said to be one of the best kinds of oak for joists, or where a stiff timber is desired.

It bears changes from wet to dry, and the reverse, well, and is almost unalterable when protected from the action of oxidizing agents, when in air or under water.

74. **The Sessile Fruited Oak** (*Quercus sessiliflora*) is another very valuable European timber-tree, which is most common in the German forests.

The wood is rather dark, of uniform color and grain,

heavy, hard, and quite elastic, resembling chestnut slightly in appearance. Like other varieties of oak, it is liable to warp and crack in seasoning. Its durability is equal to that of the preceding sort. It is somewhat more difficult to work.

75. The Beech (*Fagus sylvatica*) is a native of Great Britain and of Northern Europe.

Its closeness and uniformity of texture make it valuable for tool-makers and furniture manufacturers, a large proportion of ordinary English furniture being made of it. It is used in dry situations by millwrights for the cogs of mortice gears. The lighter-colored wood is best.

The American Beeches (*Fagus sylvestra* and *Fagus ferruginea*), the *white* and the *red*, are of somewhat less value, although similar in general characteristics.

It generally congregates in great quantities wherever the soil is most favorable; hundreds of acres are sometimes covered with this alone. Such tracts are familiarly called beech-woods.

Beech is used for furniture, gearing, submerged water-wheel bearings, tool handles, plane stocks, saddle-trees, wallets, chair-making, etc.

76. The Chestnut (*Castanea vesca*) is a native both of Europe and America. It attains a height of 70 feet (20.7 metres), and a diameter in our Middle States of 6 feet (1.8 metres); its average size is about 45 feet (13.7 metres) high, and 2 feet (.6 metre) diameter.

It is a very long-lived tree, and has been known to attain the age of 1000 years. When of great age, it is invariably hollow, and valueless for timber.

It is very similar in color to white oak, although exhibiting a stronger contrast between sap and heart-wood than the latter. It is distinguished from oak very readily by the lack of marked medullary rays, and by its lightness.

The wood is of great value. It is extremely durable, lasting under water even longer than oak or elm. It is hard and compact, and, when young, tough and flexible; but it acquires brittleness with age. Breaking transversely, it first bends considerably, and then fractures suddenly.

FIG. 32.—THE GREAT CHESTNUT OF MOUNT ETNA.

77. The Ash (*Fraxinus excelsior*) of Europe, and the *White Ash* (*Fraxinus Americana*) of America, are very valuable timber-trees. They grow to a height of 60 feet (18.3 metres), and acquire a diameter of 20 inches (50.8 centimetres) in rich, moist, loamy soils. They have no observable sap-wood.

Their woods have many useful applications. Ash is quite similar in color to oak, and in texture to chestnut. It is straight-grained, remarkably tough and elastic, excelling in these qualities all other common woods, and answers admirably for handspikes, heavy oars, ship blocks, tool handles, the wooden portion and framing of machinery, and for wheel carriages and agricultural implements. It is durable under cover, but decays rapidly if exposed to the weather.

78. The Common Elm (*Ulmus Americana*) is a native of New England, where it attains a height of 100 feet (30.5 metres), and a diameter of 6 feet (1.83 metres) or more. It grows along river-banks and in rich soil, and is a noble, ornamental tree.

The heart-wood is brown, and the sap-wood is nearly white. The wood is porous and cross-grained, and does not split when nails are driven into it. It is most valued for its great durability in situations where it is constantly wet. It is used for piles under wet foundations, framing and sheathing around wheel pits in mills, for pumps, water-ways, the keels of ships, planking, and for flumes and water conduits. It is used also by wheelwrights.

THE EUROPEAN ELM (*Ulmus campestris* and several other species) is said to be even harder and more durable than the American, and is applied to similar uses.

It is hard, flexible, and tough, but difficult to work. The wood is used for wheel naves and rims, and for wheelwrights' use generally.

Wych Elm is the best variety.

THE CANADA ELM, or MOUNTAIN ELM (*Ulmus racemosa*), is a less valuable tree.

Its wood is close and fine-grained, flexible and tough, but it shrinks, twists, and cracks in seasoning.

79. The Locust, or *Common Acacia* (*Robinia pseudacacia*), is a flowering tree found in the mountainous and hilly portions of the country from Canada to the Southern States.

It grows rapidly, and reaches a height of 70 feet (20.7 metres), with a diameter of 4 feet (1.21 metres); but it is usually considered full-grown if 40 feet (12.1 metres) high, and a foot (.305 metre) in diameter. It is a fine ornamental tree.

The wood has a peculiar greenish-yellow color, slightly resembling boxwood. The structure is alternately very compact and quite porous; its annual rings are thus very distinctly marked.

It exhibits no medullary rays, and the wood has neither taste nor odor. It is a very valuable timber, especially, for fence-posts and rails, or boarding, but is seldom found of sufficient size and quantity to be used in the latter form. It turns well in the lathe, but otherwise is difficult to cut and work. It has great torsional strength and resilience, excelling all other common woods in this quality.

80. The Hickory, or *White Walnut* (*Carya alba*), is a tall, handsome, American timber-tree, having great value for many purposes. It is common throughout the northern and eastern portions of the United States. It grows to the height of 50 or 60 feet (15.2 or 18.3 metres), and reaches a diameter of 3 feet (.9 metre).

The wood is alternately very dense and somewhat porous, and it is one of the heaviest of our woods. It is very strong and stiff, yet elastic and tough.

The wood, when freshly cut, has a slightly bitter taste and a mild odor; it is then almost white in color, but by exposure becomes gradually darker. Its heart-wood contains brownish-colored pores.

It makes excellent cogs for mortice gears, and is well adapted for handspikes, although rather heavy, and for axles, shafts, spokes, and other wheelwrights' work.

81. The Black Walnut (*Juglans nigra*) is found throughout our Middle and Western States, and as far south as the Gulf of Mexico. The tree presents a fine appearance, attains considerable size, and yields a much-prized timber.

The wood varies considerably in quality. It is of a brown color, approaching red in some specimens, and of a dark chocolate color in others. The sap-wood is frequently quite light in color. The best wood has a fine grain and a dense structure, although usually excelled in both particulars by good mahogany. It is nearly as strong as mahogany, and is tougher. It is durable, and easily worked.

FIG. 33.—BLACK WALNUT.

It is more generally used in the United States for furniture and for ornamental purposes than any other wood, and immense quantities of it are annually worked up.

FIG 34.—CHERRY.

82. The Cherry and Plum (*Prunus*) are found both in Europe and America. The wood is excellent, quite hard, of a pale pinkish brown, or yellow color, and of close grain. It makes very neat furniture, and is used for handles of tools. As its price is about that of panel pine, it is very extensively used for hard patterns.

83. The Holly (*Ilex opaca*) is an American wood, found from Maine to Pennsylvania. The tree attains a height of 30 or 40 feet (9.1 to 12.1 metres), is distinguished by the bright red of its berries, and by its glossy leaves.

The wood is white in color, close in texture, with a beautifully fine grain. It requires to be carefully and thoroughly seasoned, and then is found most excellent for "T-squares," painted wooden wares, cabinet work, blocks for calico-printers, and for turned work.

FIG. 35.—HOLLY.

84. The Maple (*Acer*) is another American wood. It is remarkable for the beautiful variety of its grain. It is very largely used in joiners' work, and in cabinet-making. It has been used, with good results, as a packing in pump-buckets.

The *Sugar Maple*, or *Bird's-Eye Maple* (*Acer saccharinum*), produces a sap charged with sugar, and the tree is therefore called the Sugar Maple. This wood is full of small knots which give it its name, and which make it the most beautiful of our light-colored woods.

FIG. 36.—MAPLE.

85. The Dogwood (*Cornus Florida*) is a small deciduous tree attaining a height of 30 feet (9.1 metres), and bearing beautiful large white flowers. It grows from Massachusetts to Florida, in moist, rich soil.

The wood is hard, fine, and close-grained, rather difficult to work, and can be given a fine polish; it is used in making tool handles, mallets, drifts, toys, harrow-teeth, hames for harnesses, and for small articles of turned work.

86. Mahogany (*Swietenia mahogani*) is a West Indian and Central American tree, growing in greatest size and perfection in the fertile regions of Honduras, and in the valleys of Cuba.

The tree is remarkable for its beauty of form and rapidity of growth, as well as for its noble size. Specimens measuring 20 feet (6.1 metres) in circumference are often found.

Mahogany is of various shades of brownish red, quite uniform in its tints in the same piece, but varying greatly in different specimens. The texture is very uniform, and its medullary rays and annual rings are not usually very well marked. The pores are quite noticeable, and, in mahogany from the West Indian islands, are filled with a white substance which distinguishes this variety, called also *Spanish Mahogany*, from the Honduras wood. It has no perceptible taste, and but slight odor. In seasoning, it is less subject to cracking or distortion than almost any known wood, which fact, and its exceptional beauty, make it a much sought and highly prized wood for fine furniture, and for many special uses, among which those of the pattern-maker are not the least important.

FIG. 37.—MAHOGANY.

The Honduras wood, often called *Baywood*, holds glue remarkably well.

The Spanish mahogany is imported in logs measuring, often, 2 feet (.61 metre) square, and 10 feet (3.05 metres) long. The Honduras mahogany comes in logs 14 or 15 feet (4.6 metres) long, and from 2 to 4 feet (.6 to 1.2 metres) square. The former is harder, of closer grain, and darker in color than the latter, which is comparatively porous, of irregular color, and is rather a weaker wood.

Mahogany is also found in the East Indies and in Africa. It is of excellent quality, but less beautiful than the American woods. Its specific gravity is .8.

87. **Lignum-Vitæ** (*Guaiacum officinale*) is obtained from the West Indies in logs of small size, and 3 to 12 feet (.9 to 3.6 metres) long. It is the hardest and heaviest wood generally used in the arts, its specific gravity being about 1.5. The wood is dark brown in the heart, and light yellow in the sap-wood. Its immense strength and hardness make it very valuable for sheaves of pulleys, and ships' blocks, or wherever great weight and friction are to be sustained. In making sheaves, care is usually taken to turn them so as to leave a ring of sap-wood on the outside, and the heart-wood within. The sheave is thus rendered less liable to crack.

Lignum-Vitæ is used for steps of water-wheels, for the stern or outboard bearings of the screw shafts of steam-vessels, and, occasionally, for other kinds of machinery bearings. Thus used, it bears an immense pressure under water, without wear or heating, and is better in such positions than any metal. It is necessary to secure efficient lubrication with water, as, although the friction is greater than if lubricated with oil, the latter lubricant does not effectively carry away the heat developed. The "end grain" should take the wear, if possible.

88. **The Spanish Cedar** (*Cedrela odorata*) is a West Indian wood, red in color, soft, light in weight, brittle, and odorous.

It is best known as the material of which cigar-boxes are made.

89. **The Teak** (*Tectonia grandis*) is an extremely valuable East Indian wood. It is also called Indian oak. Although comparatively little known in this country, it is very extensively used in Great Britain by ship-builders. The finest qualities come from the forests of Burmah, Ceylon, Malabar, and Java, where it grows to the height of 150 feet (45.7 metres), with wide-spreading branches, and a straight, graceful trunk which is sometimes 9 feet (2.75 metres) in diameter.

The wood is said by British ship-builders to be the best in

the world for their purposes as well as for general ship-carpentry. It has some resemblance to oak in its color, but it is rather lighter, and is more uniform in density and in compactness of grain. Its specific gravity, seasoned, is about .6. It is light, strong, and durable, and is easily worked. It seasons quickly, requiring comparatively little drying. It is somewhat liable to check.

It is less frequently attacked by insects than other woods, its peculiar oily, odorous, and perhaps poisonous, sap generally preserving it from even the white ant and from the teredo. The acidity of the sap of the common oak forbids the use of iron fastenings; but the teak, to the other good qualities of oak, adds that of preserving iron embedded in it, by its oily sap.

90. Camphor Wood (*Guttifera*) is also a valuable East Indian wood. It grows to a large size.

The wood is very strong, durable, and easily worked. It weighs about 70 pounds per cubic foot (1,121 kilogrammes per cubic metre). It has a powerful odor which preserves it from the attacks of insects and of marine animals.

91. Boxwood (*Buxus Balearicus*) is usually of South European and Asiatic growth, but it is found also in America.

The tree is low, and the imported logs are seldom over a foot (.305 metre) in diameter.

The wood is yellow, brighter in color than our locust, with thin bark and numerous small knots, and is often twisted and somewhat unsound. It is extraordinarily smooth and compact in texture. It is used principally for small work. The engraver uses it almost exclusively, and it is largely used for rulers and scales, and for small turned work.

92. Ebony (*Diospyros*) is found in nearly all tropical countries. The best (*D. ebenus*) comes from Mauritius. It is black (sometimes jet black), extremely hard and heavy, with a fine, close grain. It is chiefly applied to ornamental purposes, and is used by the engineer for some kinds of model work.

A green ebony, so called (*Americanus ebenus*), is found in the West Indies.

93. Lancewood (*Uvaria lanceolata*) is brought from the West Indies. It is lighter in color than boxwood, splits easily, but is very tough, strong, and elastic. It is, therefore, well adapted for pole-springs, and is useful wherever an elastic and strong wood may be needed.

94. Greenheart (*Nectandra Rodiæi*) is brought from the West Indies and the north-east coast of South America in logs from 30 to 50 feet (9.1 to 15.2 metres) long, and from 1 to 2 feet (.61 metre) square in section.

The wood is dark green varying to dark chestnut in color, sound, straight-grained, strong, elastic, and tough. It is very heavy, having a specific gravity of about 1.15. When broken, it yields suddenly and completely. It is also very durable, resisting both weather-wear and the attacks of insects remarkably well.

It is used for ship-work, engine-keelsons, beams, and piles.

95. Rosewood (*Amyris balsamifera*) is a native of tropical America, the best wood coming from Brazil.

It is the most beautiful and highly prized of the dark ornamental woods. Its color is a very dark brown, or nearly black, shading off in spots into a deep, rich, brownish red, and presenting a beautiful variety of color and of patterns in its grain. It is hard and heavy, rather difficult to work, and takes a beautiful polish. It is largely used in the form of veneers.

96. Timber is measured, when bought in market, either by the cubic foot or by *board measure*. The unit of the latter is the square foot of one inch thickness, and is denoted by the abbreviation B.M.

Sawed or hewed timber is often measured by the cubic foot. Round timber is measured by multiplying the length by the square of one-fourth its mean girth to obtain the cubic contents.

If L = the length in feet, and C the mean circumference of the log, *i. e.*, the half sum of the girth at the ends, also measured in feet, the volume in cubic feet,

$$V = L\left(\frac{C}{4}\right)^2 = \frac{LC^2}{16}.$$

Where the length is in feet and the girth in inches, find the value as above, and divide by 144 to obtain the number of cubic feet.

Oak timber should measure in the shortest logs one foot or more in length for each inch in diameter. Timber supplied for general purposes is usually cut to a standard length for convenience of measurement.

CUPRESSUS SEMPERVIRENS.

CHAPTER III.

STRENGTH OF TIMBER;

Its Special Adaptations and its Preservation.

97. The woods vary immensely in strength, and even in the same kind there may be a great variation among several specimens, arising from differences of age, and of climate, soil, exposure, seasoning, any circumstances, in fact, which may differently affect each individual tree. Wherever a definite statement of strength is hereafter given, it will be understood that it applies to well-preserved and well-seasoned mature specimens of the kind referred to.

As a general rule, the heart-wood of the tree is strongest and most uniform in character. If the tree has begun to decay while standing, however, the heart-wood is first affected.

A tree, sound when felled, decays externally first, the sap-wood usually rotting away much sooner than the heart.

The pines are rich in resin, which is an excellent preservative, and as it abounds principally in the heart-wood, knotty portions of these trees are almost indestructible by exposure to the atmosphere. It is evident that experience and excellent judgment are required to determine when the tree has arrived at just the proper age to yield the best and strongest timber. After the tree has been felled, the strength of its wood is largely influenced by the method of seasoning. If this be done gradually and thoroughly, the seasoned wood is far stronger than the green; sometimes it is of double strength.

If seasoned in oil, as described in the section (§ 41) on seasoning, the strength of hickory has been found by Mr. Geo. H. Corliss, who first made the most successful experiments, to be upwards of fifteen per cent. greater than good specimens seasoned in the usual manner. This is confirmed by Hirn, who found a gain due to this process of from ten to twenty per cent. with various woods.

Different portions of the same timber may vary considerably in strength in consequence of the existence of defects, as knots or shakes, or spots where decay has commenced.

A comparison of the results obtained with the best of timber, as given by experiments, will serve, however, as a tolerably reliable guide in estimating the value of the material which it may be proposed to use.

98. Limit of Elasticity.—All materials of construction, when forcibly distorted, will yield in a degree which is within a certain limit, very nearly proportional to the forces exerted upon them. This limit can usually be taken as that at which the ratio of the amount of distortion to that of the distorting force suddenly changes, the rate of distortion largely increasing; it is not always well defined.

It is, as a rule, reached earlier with brittle than with elastic materials. With timber, Barlow found it to be reached in tension when about one-third of the breaking weight was applied; Kirkaldy, in experiments on good wrought iron, found this limit to be at about one-half the ultimate strength of that metal.

The experience of the author, and of other experimenters, indicates this elastic limit to occur at no constant value, but to vary with every material, and with almost every variation of quality in the same material. In hard and brittle materials fracture often takes place before the elastic limit is reached; in soft and ductile substances frequently no elasticity is observable, and in most cases this change occurs so gradually that the limit is not accurately determinable. Wrought iron and "low" steels are the only metals which exhibit it plainly. In the former the limit is usually found at about one-third the ultimate resistance.

The writer has proposed to call this point the *apparent* elastic limit, since it has been found that a slight set takes place under every load, and that, therefore, there is no real elastic limit in the strictest sense in which that term has been used.

Beyond this limit, distortion becomes more rapid, and finally a point is reached at which the body is torn asunder

whatever its ductility, the resistance becoming less and less until rupture is complete.

99. A Permanent Set takes place if the material is strained beyond the elastic limit, and it occurs at a point which is reached much earlier with some materials than with others. Materials strained to this extent are not necessarily weakened by the stress. It is, however, always considered advisable not to subject them to stresses which are likely to produce set.

The observable set apparently occurs with some materials as a consequence of the application of loads which are so light as to make it appear certain that this set may, in such cases, be produced without permanent injury to the materials.

The author has shown that permanent set, even approaching the limit of resistance to rupture, does not in some cases —usually in iron and steel—injure the capacity of the material to bear dead loads.*

It is supposed by some authorities to be not improbable that in many instances the sets might be reduced after some time, were the material left unstrained, and therefore that such are not properly permanent sets.

100. The Coefficient or Modulus of Elasticity is the ratio of that force which would be required to produce a certain change of form, to the amount of that distortion, whether produced by compression or extension, the distortion in all cases being within the elastic limit.

Were elasticity perfect, this quantity would be the quantity of force required to shorten or to lengthen a piece of the given material an amount equal to its original length, its original cross-section having an unit of area.

Let

K = section of a bar of prismatic form,

l = its length,

λ = the total elongation or compression,

* Trans. Am. Soc. C. E., vol. III. *et seq.*; *Journal Franklin Inst.*, 1874; *Van Nostrand's Eng. Mag.*, 1874; *Metallurgical Review*, Nos. 1, 2, 3, 1877, etc.

P = the total force producing that elongation or compression :

Then,

$\frac{P}{K}$ = force exerted on a unit of section,

$\frac{\lambda}{l}$ = the change of length per unit of length,

and, from our own definition, we will have :

$$E = \frac{P}{K} \div \frac{\lambda}{l} = \frac{Pl}{K\lambda}. \quad \ldots \ldots \quad (1).$$

Where British units are used, it represents the number of pounds per square inch of section required to elongate or compress a bar one inch for each inch in length ; or, reciprocally, $\frac{1}{E}$ represents the fractional part of an inch which each inch in length is elongated or compressed by a force of one pound per square inch of section within the elastic limit.

By the use of this formula the coefficient of elasticity for any material can be readily determined from the results of experiment.

101. The most extended and accurate experiments upon the woods were made by MM. Chevandier and Wertheim, on timber grown in the department of Vosges, France.

Their conclusions were substantially as follows :

Age affects very slightly the density of timber.

Age and exposure have a marked influence on cohesion.

Age diminishes the coefficient of elasticity after the tree has passed maturity.

The nature of the soil, and the locality in which the tree is grown, affect this coefficient. Trees grown on dry soils in northern, north-eastern, and north-western exposures furnish timber which has the highest coefficient. Muddy or wet soils with southern exposure give the lowest.

The season in which the tree is cut has no apparent effect upon the coefficient.

In fir, the thinner the annual layers, the greater the coefficient of elasticity. In other words, no difference was detected, arising from this cause.

Timber has no defined limit of elasticity. One is taken by some writers, assuming as a limit in extension that point at which the set becomes $\frac{1}{20,000}$ ofthe original length (.00,005 l). It may be taken, for purposes of estimation, at one-third or one-fourth of the breaking weight.

102. The following values of E are given by various experimenters:

TABLE V.

COEFFICIENTS OF ELASTICITY.

	BRITISH.	METRIC.
	Lbs. on Sq. In.	Kg. on Sq. Centim.
Ash	1,600,000	112,480
Box	1,800,000	126,540
Chestnut, dry	1,250,000	91,250
Elm	1,500,000	105,450
Fir, Baltic	1,800,000	126,540
Fir, New England	1,200,000	84,360
Larch	1,400,000	98,420
Lignum-Vitæ	1,000,000	70,300
Mahogany	1,400,000	98,420
Oak, English	1,700,000	119,510
Pine, Pitch	1,900,000	133,570
" Red	1,800,000	126,540
" Yellow	1,600,000	112,400
" White	1,000,000	70,380
Teak, Indian	2,100,000	147,030
Willow	1,400,000	98,420

103. The Resistance of Materials to Distortion and Rupture is thus classified:

(1.) Longitudinal:
  a. Tensile, resisting pulling apart;
  b. Compressive, resisting crushing.

(2.) Transverse:
  a. Bending, resisting cross-breaking;

b. Shearing, resisting shearing or cutting;
c. Torsional, resisting twisting.

The "*factor of safety*" is the ratio by which the ultimate resistance to fracture exceeds the proposed load; for timber it may, under ordinary conditions, be taken as a minimum, under:

Static, or "dead" load	5
Moving, or "live" load	10
Impact, or shock	10 to 20

The latter, in important work, should always, however, be made a subject of examination after calculation of resilience, and must sometimes depend on the method of strain.

The proof load, or that to which the timber in a structure is tested, should usually be below the elastic limit.

104. The Tensile Strength of timber has been very carefully determined for all useful varieties.

The *Modulus of Strength*, or *of Tenacity*, for any material, is the amount of tensile force, in pounds or kilogrammes, required to pull apart a bar having a cross-sectional area at the point of fracture of one square inch or square centimetre.

Let

K = the section of the bar,
T = the modulus of tenacity, and
P = the force required to pull it asunder,

Then

$$P = TK \quad . \quad . \quad (2); \quad K = \frac{P}{T} \quad . \quad . \quad (3); \quad T = \frac{P}{K} \quad . \quad . \quad (4);$$

from which any one quantity may be found, where the others are already known.

105. The following values for T have been collated from different authorities, the pull being always with the grain. The maximum figures are for mature heart-wood, well seasoned and well preserved.

TABLE VI.

CO-EFFICIENTS OF TENSILE RESISTANCE.

	BRITISH.	METRIC.
	Lbs. per Sq. In.	Kg. per. Sq. Cm.
Ash	10,000 to 15,000	703 to 1,055
Birch, Black	7,000 " 10,000	492 " 703
Beech	8,000 " 12,000	562 " 844
Box	10,000 " 15,000	703 " 1,055
California Spruce	12,000 " 14,000	844 " 984
Cedar, Bermuda	4,000 " 7,500	281 " 527
" Guadaloupe	5,000 " 9,500	352 " 668
Chestnut	7,000 " 10,500	492 " 738
" Horse	8,000 " 12,000	562 " 844
Cypress	4,000 " 6,000	281 " 422
Elm	8,000 " 13,000	562 " 914
Fir (New England Spruce)	5,000 " 10,000	352 " 703
" Riga	5,000 " 12,500	352 " 879
Greenheart	6,000 " 9,000	422 " 633
Holly	10,000 " 15,000	703 " 1,055
Hickory, American	10,000 " 14,000	703 " 984
Lancewood	8,000 " 15,000	562 " 10,55
Larch	6,000 " 10,000	422 " 703
Lignum-Vitæ	10,000 " 12,000	703 " 844
Locust	10,000 " 15,000	703 " 1,655
Mahogany, Honduras	5,000 " 8,000	350 " 560
" best Spanish	8,000 " 15,000	562 " 1,055
Maple	8,000 " 10,000	562 " 703
Oak, American Live	10,000 "	703 ....
" " White	10,000 "	703 ....
" English	9,000 "	633 ....
" best English	12,000 "	844 ....
Oregon Pine	9,000 " 14,000	633 " 984
Pear	7,000 " 10,000	492 " 703
Pine, Pitch	8,000 " 10,000	562 " 703
" Red	5,000 " 8,000	352 " 562
" White	3,000 " 7,500	362 " ....
" Yellow	5,600 " 12,000	352 " 844
Plum	7,000 " 10,000	492 " 703
Poplar	7,000 "	492 " ....
Spruce	5,000 " 10,000	352 " 703
Teak	10,000 " 15,000	703 " 1,055
Walnut, Black	8,000 "	562 ....
Willow	10,000 "	703 ....

Across the grain the tenacity is much less, being for the pines and spruce woods from one-tenth to one-twentieth; and in harder woods from one-sixth to one-fourth the figures just given. In oak it is one-fourth, in pine hardly one-tenth.

For large timber the tenacity as given in the table, should be reduced 25 or 30 per cent.

In bridge work it is usual to assume the value of T at 10,000 pounds (703 kilogrammes per square centimetre), and to use a factor of safety from 8 to 10. In roofs, or other structures sustaining loads not subject to vibration, six may be adopted, thus making the actual stress in bridge work from 1,000 to 1,250 (70 to 88 kilogrammes per square centimetre); and, in roofs, about 1,700 lbs. per sq. inch (120 kilogrammes per square centimetre) of cross-section, where most severely strained. Yellow pine is generally used.

106. The Resistance to Crushing Force is, with timber, largely dependent also upon the conditions of its growth, seasoning, and preservation; and upon the part of the tree from which it is obtained, as well as upon the form and proportion of the specimen.

Where the pieces tested are blocks, having a height that is not very much greater than their diameter or least thickness, wood yields to compressive force by simple crushing. Where long columns are acted upon, they yield by bending and cross-breaking. Pillars of intermediate height give way by combined crushing and cross-breaking.

Where true crushing occurs, it is assumed that the resistance is the same as that to extension, within the limit of elasticity, although this is known not to be strictly true. This resistance also varies as the area of the cross-section.

Let P = the crushing force,

K = the area of cross-section, and

C = the crushing stress for a unit of section,

we shall have

$$P = CK \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5).$$

In this case C represents the *Modulus*, or *Coefficient* of *Crushing Resistance*, and its value is found to be approximately constant where the length of the piece does not exceed ten times its least dimensions.

107. The Modulus, or **Co-efficient of Strain,** is, then,

$$C = \frac{P}{K} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6),$$

when the force P does not crush the piece. It measures the stress on a unit of cross-section.

The following *Moduli of Crushing Strength* are deduced from experiments upon pieces one inch (2.54 centimetres) in diameter, and two inches (5.08 centimetres) long.

Hodgkinson found the compressive strength of wet wood to be frequently less than half that of dry.

TABLE VII.

COEFFICIENTS OF RESISTANCE TO CRUSHING.

[In direction, parallel with fibres.]

	BRITISH.	METRIC.
	Lbs. per Sq. In.	Kg. per Sq. Cm.
Alder	6,000 to 7,000	422 to 492
Ash	4,600 " 8,000	323 " 562
Beech	8,000 " 9,000	562 " 633
Birch	6,000 " 10,000	422 " 703
" English	5,000 " 6,500	352 " 457
Box	8,000 " 10,000	562 " 703
Cedar	4,000 " 6,500	281 " 457
Cherry	5,000 " 6,500	352 " 457
Chestnut	4,000 " 4,800	281 " 337
Elm	8,000 " 10,000	562 " 703
Greenheart	10,000 " 14,000	703 " 984
Hickory	8,000 " 9,800	562 " 689
Larch	3,000 " 5,500	211 " 387
Locust	7,500 " 9,500	527 " 668
Lignum-Vitæ	8,000 " 9,600	562 " 675
Maple	5,000 " 6,000	352 " 422
Mahogany, Spanish	7,000 " 8,000	492 " 562
Oak, English	6,500 " 10,000	457 " 703
" Live	8,000 " 10,000	562 " 703
" White	5,500 " 8,000	587 " 562
Pear	..... " 7,500	537 " ...
Pine, Red	6,000 " 7,500	422 " 527
" White	5,000 " 6.000	352 " 422
" Yellow	6,500 " 10,000	457 " 703
Spruce	4,500 " 6,000	316 " 422
Teak	6,000 " 10,000	422 " 703
Walnut, Black	5,600 " 7,000	394 " 492
" White	7,500 " 9,000	527 " 633
Willow	3,000 " 6,000	211 " 422

In many cases it will be noticed that the tensile strength of wood is double its resistance to crushing, even in short pieces.

In tests hereinafter referred to the author has found the following coefficients of compression, material tested dry: *

COEFFICIENTS OF RESISTANCE TO CRUSHING.

	BRITISH.	METRIC.
California Spruce.....	9,200 to 12,800	
Oregon Pine.....	9,200 " 11,500	

Across the grain, the resistance to crushing is from 1,000 lbs. per square inch (703 kilogrammes per square centimetre) upward, with various ordinary woods, but very few experiments have been made to determine it.

A pressure of 1,000 pounds per square inch (703 kilogrammes per square centimetre) indents white pine .1 inch (.25 centimetre); yellow pine, .004 (.01 centimetre); and the hard woods to an extent which is too slight to be detected.

108. Long Pillars yield by bending. A long series of experiments were made by Hodgkinson, and his principal deductions were the following:

Flat-ended pillars, of considerable length in proportion to their diameter, offer about three times the resistance of similar pillars with rounded ends.

One end being rounded and the other flat, the pillar has a strength which is the arithmetical mean between the previous two cases.

Both ends being fixed in one case, and both rounded in another, the cross-section being equal, a pillar of a given length in the second case has no more strength than one of double that length and of the first form.

The strength of a pillar may be increased one-seventh by enlarging it in the middle.

109. Hodgkinson's Formulas; Gordon's.—Hodgkinson

* Some of the best experimental work on the strength of American woods has been done by Mr. R. G. Hatfield, and the results are published in the *American House Carpenter*, John Wiley & Sons, publishers.

deduced from experiment, for the formula of Euler, for square, flat-ended, oak timber:

$$P = 10.95 \frac{d^4}{L^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7),$$

and for red pine,

$$P = 7.81 \frac{d^4}{L^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8),$$

in which

P = crushing weight in gross tons,
d = thickness of the pillar in inches,
L = length of pillar in feet.

Where the pillar is less than thirty, and more than four or five diameters in length,

$$W = \frac{PCK}{P + \frac{3}{4} CK} \quad . \quad . \quad . \quad . \quad . \quad . \quad (9),$$

where

W = strength of the column in gross tons.
P = the strength given by the preceding formulas (7 or 8).
C = the modulus of crushing resistance given in the table.
K = the area of cross-section in square inches.

A more usual formula is, in form, that of Gordon, sometimes called Rankine's. Rankine's modification of the latter is the following; the crushing weight in pounds:

$$P = \frac{fS}{1 + \frac{l^2}{ad^2}},$$

in which S is the sectional area in square inches, a and f constants, and l and d the length and diameter in inches. He gives for the value of a and f, for timber, 188 and 7,200 respectively. The experiments of C. S. Smith give, for well-seasoned yellow pine, $f = 5{,}000$, $a = 250$.

Morin adopts Euler's rule:

$$P' = A \frac{d^4}{l^2},$$

in which P' is the load in kilogrammes, d the diameter in cen-

timetres, and l the length in decimetres. A is taken for pine timber at 160 for a safe load. This value of A varies with the modulus of resistance to compression.

It is a good practice invariably to limit the load on columns and other struts, to that which fails to cause perceptible flexure, and never to exceed that which causes deflection to a degree beyond which a great increase may be expected to occur with comparatively little additional load. This latter point is reached with from one-third to one-half the breaking load.

In making struts of timber, Laslett states that his experiments indicate that the ratio of area of cross-section in square inches to length of inches, should not be less than from 80 to 100 (using metric measures, cross-section in square centimetres = 3¼ length in metres), and that a resistance to crushing may then be anticipated of nearly the maximum obtained with cubic specimen, which conclusion is also reached by later experimenters. The relative values of timber and iron for columns are not far from the ratios of 1 to 10.

It is sometimes necessary, in very long columns, to secure stiffness, as well as strength. The following formulas are given in *Tredgold's Carpentry*, for pillars above thirty diameters long:

$$W = A\frac{d^4}{L^2} \text{ for square pillars} \quad . \quad . \quad . \quad . \quad (10).$$

$$W = A\frac{b \cdot t^3}{L^2} \text{ for rectangular, and}$$

$$W = A\frac{d^4}{1.7L^2} \text{ for cylindrical pillars,}$$

where

W = safe load in pounds,
b, t, and d = the breadth, thickness, or diameter in inches,
L = the length in feet.

The value of the coefficient A is about 1,500 for beech, chestnut, elm, and white pine; 2,000 for ash and mahogany; 2,500 for teak and Dantzic oak, and 2,200 for red pine.

110. Columns for Mills.—During the year 1881, Prof. Lanza,* of the Massachusetts Institute of Technology, conducted a series of experiments on full-sized wooden columns, for the purpose of determining what shape and proportions were best adapted for the support of mill flooring.

Two series of tests were made, also, to determine the actual crushing strength of the wood used, with the following results:

RESISTANCE TO CRUSHING.

	LBS. PR. SQ. IN.	KG. PR. SQ. CM.
Average crushing strength of Yellow Pine.....	4,392	307.5
" " " White Oak.....	3,323	232.6
" " " Whitewood	3,009	210.6

These figures are deduced from the tests of unselected material, and therefore fall considerably below those ordinarily given.

For comparison with the above the following tables, of results obtained at the Watertown Arsenal, will be found interesting:

TABLE VIII.

CRUSHING STRENGTH OF YELLOW PINE,
Very Straight Grained, Twenty Years' Seasoning.

ARSENAL NUMBER.	LENGTH.		FORM OF SECTION.	DIMENSION OF SECTION.		CRUSHING STRENGTH.		
	INCHES.	CENTIMETRES.		INCHES.	CENTIMETRES	LBS. PER SQ. IN.	KILOS. PER SQ. CM.	
573	20.4	51.82	Circular.	10.2 diam.	25.91 diam.	6,676	467.32	
578	119.95	304.67	Rectangular..	10.97 × 11	27.86 × 27.93	6,230	436.1	
579	119.9	304.67	"	10.96 × 10.96	27.85 × 27.85	6.552	458.64	
582	20	50.8	"	9 × 9	22.86 × 22.80	8,322	582,54	All from one piece of timber.
583	16	40.64	"	8.02 × 8.02	20.37 × 20.37	8,165	571.55	
584	..	.....	"	4 × 4	10.16 × 10.16	7,394	517.58	
585	3	7.62	"	1.5 × 1.5	3.81 × 3.81	5,593	387.31	
586	6	15.24	"	3 × 3	7.62 × 7.62	8,744	605.08	
587	6	15.24	"	3 × 3	7.62 × 7.62	8,133	569.31	
588	3	7.62	"	1.5 × 1.5	3.81 × 3.81	8,329	583.03	
589	3	7.62	"	1.5 × 1.5	3.81 × 3.81	8.302	581.14	
590	3	7.62	"	1.5 × 1.5	3.81 × 3.81	6,355	444.85	
Average.....						7,386	517.02	

* Boston *Journal of Commerce*, January 28, 1882.

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TABLE IX.

CRUSHING STRENGTH OF YELLOW PINE.

Very slow growth.

ARSENAL NUMBER.	LENGTH.		FORM OF SECTION.	DIMENSION OF SECTION.		CRUSHING STRENGTH.	
	INCHES.	CENTIMETRES.		INCHES.	CENTIMETRES	LBS. PER SQ. IN.	KILOS. PER SQ. CM.
591	14	35.56	Rectangular	4.6 × 4.6	11.68 × 11.68	9,947	696.29
592	17.2	43.69	"	" "	" "	10,250	717.5
593	19.1	48.51	"	5.3 × 5.3	13.46 × 13.46	7,820	547.4
Average						9,339	653.73

TABLE X.

CRUSHING STRENGTH OF YELLOW PINE.

Very green and wet.

ARSENAL NUMBER.	LENGTH.		FORM OF SECTION.	DIMENSION OF SECTION.		CRUSHING STRENGTH.	
	INCHES.	CENTIMETRES.		INCHES.	CENTIMETRES	LBS. PER SQ. IN.	KILOS. PER SQ. CM.
691	180	459	Open rect.	16 × 13.65	40.64 × 34.67	3,070	212.1
692	180	459	"	16.2 × 7	41.15 × 17.78	2,795	195.65
714	180	459	"	17 × 8.75	44.18 × 22.22	3,180	222.6
Average						3,015	211.05

TABLE XI.

CRUSHING STRENGTH OF SPRUCE.

ARSENAL NUMBER.	LENGTH.		FORM OF SECTION.	DIMENSION OF SECTION.		CRUSHING STRENGTH.	
	INCHES.	CENTIMETRES.		INCHES.	CENTIMETRES	LBS. PER SQ. IN.	KILOS. PER SQ. CM.
565	24	60.96	Rectangular.	5⅜ × 5⅜	13.65 × 13.65	4,946	346.22
566	24	60.96	"	" "	" "	4,811	336.77
567	36	91.44	"	" "	" "	4,874	340.98
568	36	91.44	"	" "	" "	4,500	315.00
569	60	152.4	"	" "	" "	4,451	311.57
570	60	152.4	"	" "	" "	4,943	346.01
571	120	304.68	"	" "	" "	3,967	277.67
572	120	304.68	"	" "	" "	4,908	343.56
	60	112.4	"	" "	" "	5,275	369.25
	30	7.62	"	" "	" "	5,372	376.04
	15	38.08	"	" "	" "	5,754	402.78
977	121.2	307.85	Circular.	12.4 diam.	31.5	4,681	327.67

Thus we have the following average values for crushing strength of yellow pine:

TABLE XII.

RESISTANCE TO CRUSHING.

	LBS. PER SQ. IN.	KLS. PR. SQ. CM.
Pine, straight grained, well seasoned, Arsenal test	7,386	517.02
" slow growth, " " " "	9,339	653.73
" very green and wet, " "	3,015	211.05
" as used in Lanza's tests.....	4,400	308.00
" C. Shaler Smith's tests.....	5,000	350.00

This shows a great variation between the figures of carefully made and authentic tests. These differences are evidently due both to the selection of timber and to the seasoning of material.

Lanza recommends that columns should be bored from one end only, and this boring should extend throughout the length of the column. When columns are bored from both ends so as to meet in the middle, the two borings are apt to be eccentric, thereby weakening the piece.

The object of the boring is to allow free access of the air to all parts of the wood.

III. **Resistance to Shearing** is offered when it is attempted to divide the piece by a pair of forces acting along the same line in opposite directions, and parallel to the plane of separation.

The shearing may take place in the case of timber, either along the grain on a plane parallel to the direction of the fibre, or across the grain in the same plane, or it may take place in a plane to which all the fibres are perpendicular. In each of these three cases, the modulus of shearing resistance has a different value.

In each case the resistance is proportional to the area of the section ruptured, and is generally independent of its form. Where, however, the form is such that all parts of the section strained cannot act together in resisting shearing, the modu-

lus may be greatly reduced. Where, for example, the section is long and narrow, it will yield far more readily when attacked at the narrow, than when the shearing begins on the wider side.

The following values of the *Modulus of Shearing*, are given by R. G. Hatfield for cases where the force acts along the grain, and parallel with the fibres:

TABLE XIII.

COEFFICIENT OF DETRUSIVE SHEARING.

	BRITISH.	METRIC.		BRITISH.	METRIC.
	Lbs. per Sq. Inch.	Kg. per Sq. Cm.		Lbs. per Sq. Inch.	Kg. per Sq. Cm.
Chestnut.....	690	48	Pine, Ohio.....	388	27
Hemlock.....	540	38	" Spr'ce (Fir)	470	33
Locust.....	1,180	83	" White....	490	34
Oak.....	780	55	" Yellow...	510	36

A knowledge of this modulus is necessary in properly proportioning the joints in tie-beams, and the depth of notches at the foot of rafters.

The following are values of the modulus of detrusive shearing in cases where the force acts perpendicular to the fibres:

TABLE XIV.

COEFFICIENTS OF DETRUSIVE SHEARING ACROSS THE GRAIN.

	BRITISH.	METRIC.		BRITISH.	METRIC.
Larch (Hackmatack)	1,000	70	Red Pine.....	800	56
Oak.....	4,000	280	Spruce Pine.....	600	42

Trautwine obtains by experiment the following values of the shearing resistance of American woods, where rupture is produced across the axis of the piece.

TABLE XV.

RESISTANCE TO TRANSVERSE SHEARING.

WOODS.	LBS PER SQ. INCH.	KGS. PER SQ. CM.	WOODS.	LBS. PER SQ. INCH.	KGS. PER SQ. CM.
Ash.....	6,280	440	Hickory.....	6,045 to 7,285	23 to 511
Beech.....	5.223	366	Locust.....	7,176	503
Birch.....	5,595	392	Maple.....	6,355	445
Cedar, White.	1,372 to 1,519	96 to 107	Oak, White...	4,425	310
" C. Am.	3,410	239	" Live....	8,480	595
Cherry.....	2,945	206	Pine, White ..	2,480	174
Chestnut.....	1,535	108	" Yellow.	4,340 to 5,735	304 to 402
Dogwood....	6,510	456	Poplar.....	4,418	310
Ebony... ...	7,750	543	Spruce.....	3,255	228
Gum.....	5,890	413	Walnut, Black	4,725	331
Hemlock.....	2,750	193	Walnut, White	2,830	199

Fairbairn found that the resistance offered to forcing a ball three inches (7.62 centimetres) in diameter, through three-inch (7.62 centimetres) oak plank, was about the same as with quarter-inch (.63 centimetre) boiler plate, 17,000 pounds (7,727 kilogrammes).

112. Rupture by Cross-breaking more frequently occurs with timber than any other kind of rupture, owing to the fact that it is more usually subjected to cross strains in situations where it is generally applied.

The relation between the stress and the character of the molecular change which it produces, has been made a subject of frequent mathematical investigation from the time of Galileo, who seems to have been the first to attack the problem analytically. Such discussions have properly no place here, as the engineer will learn the theory of the subject from special treatises on strength of materials.*

113. Formulas for Cross-breaking.—The following formulas have been derived for solid beams of rectangular section:

In these expressions R = a constant coefficient, and represents the stress on the fibre most distant from the neutral axis on that side which first gives way; l = the length, and b and d = the breadth and depth of the beam in question. W represents the distributed load on the beam, and P a single force applied at a given point.

*See Wood's *Resistance of Materials*, N. Y., J. Wiley & Sons, 1877.

For a beam firmly *fixed* at one end, and loaded at the free extremity:

$$P = \frac{Rbd^2}{6l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11).$$

Same beam uniformly loaded,

$$W = \frac{Rbd^2}{3l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12).$$

Beam *supported* at both ends, loaded in the middle,

$$P = \frac{2Rbd^2}{3l} \quad . \quad . \quad . \quad . \quad . \quad . \quad (13).$$

Same beam uniformly loaded,

$$W = \frac{4Rbd^2}{3l} \quad . \quad . \quad . \quad . \quad . \quad . \quad (14).$$

Same beam uniformly loaded, and also loaded in the middle,

$$2P + W = \frac{4Rbd^2}{3l} \quad . \quad . \quad . \quad . \quad . \quad (15).$$

$$P = \frac{2Rbd^2}{3l} - \frac{W}{2} \quad . \quad . \quad . \quad . \quad . \quad (16).$$

$$W = \frac{4Rbd^2}{3l} - 2P \quad . \quad . \quad . \quad . \quad . \quad (17).$$

Beam *fixed* at both ends, loaded at the middle,

$$P = \frac{4Rbd^2}{3l} \quad . \quad . \quad . \quad . \quad . \quad . \quad (18).$$

Same beam uniformly loaded,

$$W = \frac{8Rbd^2}{3l} \quad . \quad . \quad . \quad . \quad . \quad . \quad (19).$$

Same beam with uniform load at end section,

$$\frac{1}{12} Wl = \frac{Rbd^2}{6} \quad . \quad . \quad . \quad . \quad . \quad . \quad (20).$$

Same beam, same load at middle section,

$$\frac{1}{24} Wl = \frac{Rbd^2}{6} \quad . \quad . \quad . \quad . \quad . \quad . \quad (21).$$

It is seen that in such beams the strength is proportional to their breadths, and to the square of their depths, and is inversely as their lengths.

Where this beam is fixed at both ends, it is found in all actual cases that the formula gives it credit for more strength than it really has, and that it is more liable to break in the middle than at either end, although the analysis which determines the formula indicates that this liability is the same at each of the three points. Barlow has therefore recommended for the special case that formula (18).

$$P = \frac{Rbd^2}{l},$$

as more nearly approaching the conditions of every-day practice.

The discrepancy probably arises from the fact, that in practice the beam is not perfectly "fixed" in the sense in which that word is used above.

114. The Neutral Axis of a beam is that line of particles which, under the given transverse stress, is not subjected to either tensile or compressive longitudinal strain.

115. The Modulus of Rupture is a quantity which is represented in the formulas by R, and is determined for each material by experiment.

It represents the stress upon a unit of area of cross-section of the fibre farthest from the neutral axis on the side which gives way, and at the instant of breaking under transverse stress. Although it would seem that it should be equal to the tenacity of the material where rupture occurs on the extended side, and to the compressive strength of the material where the beam yields by crushing, it is found by experiment to be intermediate between the two values in all cases. Thus, with oak having a tenacity of 17,000 pounds per square inch (1,190 kilogrammes per square centimetre), and a

strength to resist crushing of 9,500 pounds (665 kilogrammes per square centimetre), the value of R has been found to be about 10,000. With ash, the same quantities are respectively 17,000, 9,000, and 12,000 pounds per square inch.

116. The following values of R, the modulus of rupture, in (11) to (21), have been determined by various authorities, and are given as close approximations for timber in good condition. The units are pounds and inches, kilogrammes and centimetres.

TABLE XVI.

MODULI OF RUPTURE OF WOODS.

	BRITISH.	METRIC		BRITISH.	METRIC
Ash	12,000	844	Lignum-Vitæ	12,000	844
Beech	9,000	633	Locust	12,000	844
Birch, American	9,500	668	Mahogany, Spanish	8,000	562
Box	8,500	598	" Honduras	10,000	703
Cedar, West Indian	8,000	562	Maple	8,000	562
" United States	8,000	562	Oak, Canadian	10,000	703
Chestnut	7,000	492	" English	10,000	700
Ebony, West Indian	15,000	1,055	" European	10,000	703
Elm	8,000	562	" Live	12,000	844
Fir, New England	7,000	492	" White	11,000	773
" Riga	7,000	492	Pine, Pitch	8,000	562
" Norway	7,000	492	" Red	8,000	562
" American Spruce	7,000	492	" Yellow	7,000	492
Greenheart	10,000	703	Teak	15,000	1,055
Lancewood	15,000	1,055	Walnut	12,000	844
Larch, European	8,000	762	Willow	7,000	492
" American	10,000	703			

117. From the records of about forty tests of California spruce and Oregon pine, made by the Author at the Stevens Institute of Technology for the U. S. Geological Survey during the year 1880, the following results are taken:

TABLE XVII.

MODULUS OF RUPTURE (MEAN).

	BRITISH.	METRIC.
California Spruce	12,228	845
Oregon Pine	11,071	775

Beams of the same material vary greatly in strength, and they sometimes break under one-fourth the load corresponding to their coefficients as above given, even when apparently sound. A large factor of safety is hence advisable.

118. A solid cylinder varies in strength as the cube of its diameter. The formula for this case becomes, where fixed at one end and loaded at the other,

$$P = \frac{Rd^3}{1.7 \times 6 \times l} \quad . \quad . \quad . \quad . \quad . \quad . \quad (22),$$

and if uniformly loaded this value P is doubled. Supported at the ends and loaded in the middle, P becomes quadrupled; supported at both ends and uniformly loaded, it is eight times as great.

A beam *supported* at one end, *fixed* at the other, and loaded uniformly, has the same strength as the last case, as has also a beam fixed at both ends, and loaded in the middle. When fixed at both ends and uniformly loaded, the value of P is twelve times as great as in the first of the preceding cases. The latter statement of the relative strength of beams differently placed is correct for all solid beams.

A wooden beam of triangular section, supported at both ends, is about *one-sixth* stronger with its base upward than with its base downward.

The strongest beam of rectangular section that can be cut from a round log, has a breadth proportioned to its depth, as $\sqrt{2}$ is to 1, or nearly as 7 to 5. Such a beam is ten per cent. stronger than the beam of square section that might be cut from the same log. The most resilient beam has its breadth and depth equal. Placing the beam with its annual layers in the plane in which the load acts increases its resistance in the proportion of 8 to 7 nearly.

The following, in British measures, are the dimensions and safe distributed loads of sound pine beams, for each inch of thickness, as used in ordinary work.

In metric measures the loads are approximately metric "*tonnes*," of 1,000 kilogrammes, for depths in centimetres as given, and per ¼ decimetre width.

TABLE XVIII.

LOADS ON YELLOW PINE BEAMS.

SAFE UNIFORMLY DISTRIBUTED LOADS IN TONS OF 2,000 LBS. FOR RECTANGULAR BEAMS ONE INCH IN THICKNESS.

Span in feet.	DEPTH IN INCHES AND CENTIMETRES.															
	1 2.5	2 5.0	3 7.5	4 10.0	5 12.5	6 15.0	7 17.5	8 20.0	9 22.5	10 25.0	11 27.5	12 30.0	13 32.5	14 35.0	15 37.5
1	0.069	0.278	0.625	1.111	1.736	2.500	3.403	4.444	5.625	6.944	8.403	10.000	11.737	11.611	15.625
2	0.035	0.139	0.312	0.556	0.868	1.250	1.701	2.222	2.812	3.472	4.201	5.000	5.868	6.806	7.812
3	0.023	0.093	0.208	0.370	0.579	0.833	1.134	1.481	1.875	2.315	2.801	3.333	3.912	4.537	5.208
4	0.017	0.069	0.156	0.278	0.434	0.625	0.851	1.111	1.406	1.738	2.101	2.500	2.934	3.403	3.906
5	0.014	0.056	0.125	0.222	0.347	0.500	0.681	0.888	1.125	1.389	1.681	2.000	2.347	2.722	3.125
6	0.012	0.046	0.104	0.185	0.289	0.417	0.567	0.741	0.938	1.157	1.400	1.667	1.956	2.269	2.604
7	0.010	0.040	0.089	0.159	0.248	0.357	0.486	0.635	0.804	0.992	1.200	1.429	1.677	1.944	2.232
8	0.009	0.035	0.078	0.139	0.217	0.312	0.425	0.555	0.703	0.868	1.050	1.250	1.467	1.701	1.953
9	0.008	0.031	0.069	0.123	0.193	0.278	0.378	0.494	0.625	0.772	0.934	1.111	1.304	1.512	1.736
10	0.007	0.028	0.062	0.111	0.174	0.250	0.340	0.444	0.562	0.694	0.840	1.000	1.174	1.361	1.562
11	0.006	0.025	0.057	0.101	0.158	0.227	0.309	0.404	0.511	0.631	0.764	0.909	1.067	1.237	1.420
12	0.006	0.023	0.052	0.093	0.145	0.208	0.284	0.370	0.469	0.579	0.700	0.833	0.978	1.134	1.302
13	0.005	0.021	0.048	0.085	0.134	0.192	0.261	0.342	0.433	0.534	0.646	0.769	0.903	1.047	1.202
14	0.005	0.020	0.045	0.079	0.124	0.179	0.243	0.317	0.402	0.496	0.600	0.714	0.838	0.972	1.116
15	0.005	0.019	0.042	0.074	0.116	0.167	0.227	0.296	0.375	0.463	0.560	0.667	0.782	0.907	1.042
16	0.004	0.017	0.039	0.069	0.109	0.156	0.213	0.278	0.352	0.434	0.525	0.625	0.734	0.851	0.977
17	0.004	0.016	0.037	0.065	0.102	0.147	0.200	0.261	0.331	0.408	0.494	0.588	0.695	0.801	0.919
18	0.004	0.015	0.035	0.062	0.096	0.139	0.189	0.247	0.312	0.386	0.467	0.556	0.652	0.756	0.868
19	0.004	0.015	0.033	0.058	0.091	0.132	0.179	0.234	0.296	0.365	0.442	0.526	0.617	0.716	0.822
20	0.003	0.014	0.031	0.056	0.087	0.125	0.170	0.222	0.281	0.347	0.420	0.500	0.587	0.681	0.781
21	...	0.013	0.030	0.053	0.083	0.119	0.162	0.212	0.268	0.331	0.400	0.476	0.559	0.648	0.744
22	...	0.013	0.028	0.051	0.079	0.114	0.155	0.202	0.256	0.311	0.382	0.455	0.533	0.619	0.710
23	....	...	0.027	0.048	0.075	0.109	0.148	0.193	0.245	0.302	0.365	0.435	0.510	0.592	0.679
24	...	...	...	0.046	0.072	0.104	0.142	0.185	0.234	0.289	0.350	0.417	0.489	0.567	0.651
25	...	...	...	...	0.069	0.100	0.136	0.178	0.225	0.278	0.336	0.400	0.469	0.544	0.625
26	...	...	...	...	...	0.096	0.131	0.171	0.216	0.267	0.323	0.385	0.451	0.524	0.601
27	...	...	...	...	...	...	0.126	0.165	0.208	0.257	0.311	0.370	0.435	0.504	0.579
28	...	...	...	...	...	...	...	0.159	0.201	0.248	0.300	0.357	0.419	0.486	0.558
29	...	...	...	...	...	...	...	...	0.196	0.239	0.290	0.345	0.405	0.469	0.539
30	...	...	...	...	...	...	...	...	...	0.231	0.280	0.333	0.391	0.454	0.521

These loads are about one-eighth the breaking load. Beams supported.

RULE.—*To find the safe uniformly distributed load* for yellow pine beams, multiply the number given in the table by the thickness of the beam in inches, or take 0.4 the given number for load per centimetre of thickness. For beams of other wood, multiply by the following numbers:

White Oak.	White Pine.	Hemlock.	White Cedar.	Spruce.
1.45	.95	.95	.65	.85

119. The Stiffness of Beams varies as their breadths, and as the cube of their depths.

As the strength only varies as the square of the depth, it follows that large beams will be found to bend less, before breaking, than will small beams. From this fact, also, it happens that it becomes necessary, with flexible wood of comparatively small scantling, to proportion them to bear a given load with a certain limited deflection, rather than with reference to their absolute strength. In using any material the necessity frequently arises for employing formulas, expressing stiffness rather than strength, in order to secure the requisite rigidity of parts.

The stiffest beam which can be cut from a round log has its breadth and depth proportioned as 1 is to $\sqrt{3}$, or nearly as 1 to 1.732 = ·577+ to 1.

120. Formula for Flexure.—The following formula represents the flexure of beams of rectangular section, lying on two supports, and loaded in the middle:

Let D = the deflection, in inches or centimetres,
L = the length between bearings, in feet or metres,
P = the weight, in pounds or kilogrammes,
b and d = the breadth and depth, in inches or centimetres:

$$D = \frac{CPL^3}{bd^3} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23).$$

C is a constant determined by experiment for each material. On page 99 are its values as given by the best authorities. In metric measure $C_m = C \times 8000$, nearly.

It is generally assumed that timber should not be loaded to a deflection greater than $\frac{1}{360}^{th}$ its length. In such cases, $30D = L$, and, substituting this value, we get from (23), British measures:

$$C = \frac{bd^3}{30L^2P}, \quad \text{and} \quad P = \frac{bd^3}{30L^2C} \quad . \quad . \quad . \quad (24).$$

Where beams are fixed at one end and loaded at the other, they deflect 16 times as much as when supported at

both ends, and loaded in the middle.* Hence, for this case, the values of C above given must be increased in this proportion; the formula then becoming

$$D = \frac{16PL^3C}{bd^3} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25).$$

TABLE XIX.

COEFFICIENTS OF DEFLECTION.

	BRITISH.	METRIC		BRITISH.	METRIC
Ash	0.00030	2.5	Maple	0.00040	3.0
Beech	0.00030	2.5	Mahogany, Spanish	0.00030	2.5
Birch	0.00030	2.5	" Honduras	0.00025	2.0
Cedar	0.00030	2.5	Oak, minimum	0.00025	2.0
Cherry	0.00040	3.0	" maximum	0.00050	4.0
Chestnut	0.00025	2.0	" mean value	0.00040	3.0
" Spanish	0.00050	3.5	Pine, White	0.00025	2.0
Elm	0.00030	2.5	" Pitch	0.00030	3.5
Fir, Am. Spruce	0.00025	2.0	Teak	0.00030	2.5
" Norway	0.00025	2.0	Walnut	0.00025	2.0
Larch	0.00030	2.5	Willow	0.00060	5.0

If, in this latter case, the load should be uniformly distributed, the formula becomes (l, b, d, are in inches):

$$D = \frac{0.625CPl^3}{bd^3} \quad . \quad . \quad (26); \qquad D = \frac{12Pl^3C}{bd^3} \quad . \quad . \quad (27).$$

The formulas just given for the deflection of beams are those most generally used. A less simple, but possibly more accurate formula has been proposed by Prof. W. A. Norton, and is well supported by the experiments from which he deduces it. Δ = the deflection of a piece supported at the ends, loaded at the middle:

$$\Delta = \frac{Pl^3}{4Ebd^2} + C\frac{Pl}{bd} \quad . \quad . \quad . \quad . \quad . \quad (28).$$

C is given at 0.0,000,094; E = 1,427,965 pounds.

* Trautwine gives 24 for beams as fixed in practice.

121. Beams should be made as deep as possible, provided they are not made of such depth as to be liable to overturn and break sideways. A formula to determine the proper proportions of section is the following, which is given for use in general practice:

$$b = 0.6\frac{L}{\sqrt{d}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (29).$$

The *stiffest* rectangular beam that can be cut from any cylindrical log has its thickness equal to one-half the diameter of the log. Beams of square section are equally stiff in whatever direction they may be bent. A beam fixed at both ends has twice as great stiffness as one merely supported.

In framing, therefore, the joists should be made of as great length as possible, in order that they may extend over the greatest number of supports; and they should invariably be notched over the latter, where possible.

122. Working Loads for Floor-beams.—C. J. H. Woodbury, of Boston, Mass.,* gives the following formulas, deduced from experiments on beams used in mill floors. The measures, as will be seen, are all British:

Let h = depth of beam, inches.
b = breadth of beam, inches.
d = deflection, inches.
l = span, feet.
s = width of load, feet.
w = distributed load per square foot of floor, including its own weight, lbs.
a = weight of floor per square foot, lbs.
w' = distributed load upon square foot of floor, not including weight of floor, in lbs.
W = concentrated load on floor, lbs.
R = modulus of rupture, lbs. per square inch.

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* See a paper read before the American Society of Mechanical Engineers (1881), and *Fire Protection of Mills*, by C. J. H. Woodbury; N. Y., J. Wiley & Sons, 1882.

E = modulus of elasticity, lbs. per square inch.
f = factor of safety, in units.

Assuming the following data:

	SOUTHERN PINE.	SPRUCE.
E =	2,000,000,	1,200,000;
R =	12,960,	10,080.

That in storehouse floors,

$f = 6$, for fixed loads; $2f = 12$, for live loads.

The limit of d in mill floors, .075 inch per 8 feet, say $\frac{1}{1200}$ span. For 25 feet beams, same curvature = about .75 inch = $\frac{1}{400}$ span.

We find: In a beam loaded at centre and supported at ends,

$$R = \frac{18Wl + 9wl^2}{bh^2}; \qquad E = \frac{432Wl^3}{bh^3d} \quad \ldots\ldots (30).$$

Strength of beams. Load uniformly distributed:

$$w = \frac{Rbh^2}{9fsl^2}; \qquad l = \sqrt{\frac{Rbh^2}{9wfs}}; \qquad h = \sqrt{\frac{9wfsl^2}{Rb}} \quad \ldots\ldots (31).$$

Strength of floor plank Load in bulk (as grain):

$$w = \frac{4Rh^2}{3fl^2}; \qquad l = \sqrt{\frac{4Rh^2}{3wf}}; \qquad h = \sqrt{\frac{3wfl^2}{4R}} \quad \ldots\ldots (32).$$

Strength of floor plank. Load in case or bale:

$$w' = \frac{4Rh^2 - 3afl^2}{12fl}; \quad l = \sqrt{\frac{4Rh^2}{3f(4w' + u)}};$$

$$h = \sqrt{\frac{3fl^2(4w' + u)}{4R}} \quad \ldots\ldots (33).$$

Then in a storehouse, with floors of spruce plank; beams of Southern yellow pine, 8 feet between centres, and height of beam = twice breadth.

The strength of beams:

$$w = \frac{15h^3}{l^2}; \qquad l = \sqrt{\frac{15h^3}{w}}; \qquad h = \sqrt[3]{\frac{wl^2}{15}} \quad \ldots\ldots (34).$$

Strength of floor plank:

$$w' = \frac{35h^2 - u}{4}; \quad l = \sqrt{\frac{2240h^2}{4w + u}}; \quad h = \sqrt{\frac{4w' + u}{35}} \quad \ldots (35).$$

Deflection of beams:

$$d = \frac{270wsl^4}{Ebh^3}; \qquad w = \frac{Ebh^3d}{270sl^4}; \qquad h = \sqrt[3]{\frac{270wsl^4}{Ebd}} \quad \ldots\ldots (36).$$

Deflection of floor plank *one* bay in length—a form of construction not advised:

$$d = \frac{45wl^4}{2Eh^3}; \qquad w = \frac{2Edh^3}{45l^4}; \qquad h = \sqrt[3]{\frac{45wl^4}{2Ed}} \quad \ldots\ldots (37).$$

Deflection of floor plank *two* bays in length:

$$d = \frac{28wl^4}{3Eh^3}; \qquad w = \frac{3Edh^3}{28l^4}; \qquad h = \sqrt[3]{\frac{28wl^4}{3Ed}} \quad \ldots\ldots (38).$$

123. Torsional Strains rarely occur with timber, and but little has been definitely known, until recently, of the value of the different woods to resist this kind of stress.

Rupture by torsion will take place by *shearing* the fibres, if the planes in which the opposing couples producing rupture act are identical in position, or nearly approach each other. If these planes are more widely separated, the beam will be broken by combined shearing and tension of the fibres, or even, in extreme cases, by tensional stress alone.

The *angle of torsion* is that angle through which a fibre will be turned by the twisting force where the fibre is a unit in length, and is situated at a unit's distance from the axis.

The *total angle of torsion* is the angle which measures the *relative* angular motion of the torsional and resisting lever arms.

The coefficient of elastic resistance to torsion is the force required to turn a hollow shaft of the given material, a unit of area in section, and a unit in length, through an *angle, unity.*

Let α = total angle through which a radius is twisted,

θ = the *angle of torsion*, $= \frac{\alpha}{l}$,

l = the length of the part twisted,

a = the lever arm of the twisting force P,

r = the radius of the cylinder,

γ = a coefficient used in (39) and equal to $\frac{2}{\pi G}$,

G = the coefficient of elastic resistance.

Then

$$\theta = \frac{\alpha}{l} = \frac{2Pa}{\pi r^4 G} = \frac{\gamma Pa}{r^4} \quad . \quad . \quad . \quad . \quad . \quad (39).$$

From these equations we get

$$G = \frac{2Pa}{\pi\theta r^4} = \frac{2Pal}{\pi\alpha r^4} \quad . \quad . \quad . \quad . \quad . \quad (40),$$

and hence by experiment we can determine G and γ.

The following values were determined in British measure by the Author, who used a machine designed for the purpose, which recorded its own action by pencilling a curve whose abscissas represented twisting moments, and whose ordinates represented the corresponding values of θ.*

TABLE XX.

COEFFICIENTS OF TORSION.

	G.	γ.
Ash	410,000	0.001,055
Cedar, Red	890,000	0.000,701
Chestnut	355,000	0.001,783
Hickory	910,000	0.000,695
Locust	1,225,000	0.000,517
Mahogany	660,000	0.000,960
Oak	570,000	0.001,111
Pine, Spruce	211,000	0.003,000
" Yellow	495,000	0.001,280
" White	220,000	0.002,880
Walnut, Black	582,000	0.001,090

124. When *Rupture by Torsion* occurs, the outer layers of fibres will be broken first. Up to the limit of elasticity of these fibres, the strain upon any one fibre will vary approximately as its distance from the axis of torsion.

Where C = coefficient of rupture,
d = the diameter, in inches or centimetres,
P = the twisting force, in pounds or kilogrammes,
l = the lever arm of P.

We shall have for cylindrical pieces,

$$P = \frac{C\pi r^3}{2l}; \qquad r = \sqrt[3]{\frac{2Pl}{C\pi}} \quad . \quad . \quad . \quad . \quad (41).$$

* *Journal Franklin Institute* for 1873, p. 254.

The following values for A have been determined by the Author by experiments with recording apparatus, and for the simplified equations

$$d = \sqrt[3]{\frac{Pl}{A}} \quad . \quad . \quad . \quad (42), \text{ and } P = \frac{Ad^3}{l} \quad . \quad . \quad . \quad . \quad (43).$$

TABLE XXI.

COEFFICIENTS OF TORSION.

	METRIC.	BRITISH.		METRIC.	BRITISH.
Ash	.328	41.0	Black Spruce	.216	27.0
Cedar, Red	.244	30.5	Heart	.264	33.0
Chestnut	.296	37.0	Sap	.316	39.5
Hickory	.644	80.5	Pine, Spruce	....	....
Locust	.648	81.0	" White	.185	23.1
Oak	.424	53.0	" Yellow	....	....
Mahogany, Spanish	.524	65.5	Walnut, Black	.412	51.5

Cauchy makes C about four-fifths the value of the coefficient of transverse rupture; but this relation must probably be variable.

125. **Resilience,** as the term is here used, measures the power of resisting shock. It is the amount of work performed, or of energy expended, in producing distortion or rupture, whether by steadily applied stress or by impact.

Resilience is measured by the sum of the products of all resistances into the distance through which those resistances act. Its value depends—in tension, upon tenacity, elasticity, and ductility; in compression, upon compressive resistance, elasticity, and plasticity; in shearing, upon shearing resistance and elasticity; in transverse distortion, upon transverse resistance and flexibility; and in torsion, upon torsional resistance, elasticity, and, to a certain extent, ductility.

Resilience is frequently expressed graphically by curves, Fig. 38, whose ordinates, x, are proportioned to the distortions, and whose abscissas, y, are proportioned to the loads. As, up to the limits of elasticity, the amounts of resistance and distortion may be considered, practically, to increase uniformly, and maintain a constant ratio to each other, the plotted results will show, Ad = distortion, ad = load at elastic limit, and, because of the constant ratio between distortion and load, Aa will be a straight line. The *elastic resilience* will be represented by the area of the triangle Aad, which area is one-half the product of the load, y, into the distortion, x.

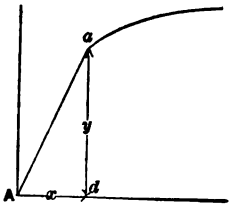

FIG. 38.

Elastic resilience is measured by one-half the product of the load at the elastic limit, in pounds or kilogrammes, into the distortion due to that load, in inches or metres; the result is in inch-pounds or kilogramme-metres.

Beyond the elastic limit, the behavior of the bar depends upon its peculiar properties, and therefore no general law can express resilience for all materials. Care must be taken in applying coefficients, rules, and formulas, to ascertain how far they are applicable to specific cases. Any one coefficient, rule, or formula for *ultimate resilience* can apply only to materials having similar properties.

The resilience which is expressed by half the product of the maximum resistance into the maximum distortion, applies only to non-ductile materials in which the elastic limit coincides with the point of rupture. It gives the *resilience of timber* with a fair degree of accuracy. For some very ductile materials the ultimate resilience will approximate the product of the maximum load and maximum distortion.

Calling R the resilience at the elastic limit; P the load at the elastic limit; and D the distortion under the load,

$$R = \frac{PD}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (44).$$

If using coefficients of distortion, C, where the actual distortion is PC,

$$R = \frac{P \times PC}{2} = \frac{P^2 C}{2} \quad . \quad . \quad . \quad . \quad . \quad (45).$$

If the coefficient is the coefficient of elasticity, E, the distortion is $\frac{P}{E}$, and the formula becomes,

$$R = \frac{P^2}{2E} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (46).$$

The torsional resilience at the elastic limit is one-half the product of the moment of resistance into the corresponding angle of torsion. Pa = force × leverage = moment of resistance, α = total angle of torsion (page 103) in degrees, then

$$R = \frac{Pa \times \alpha}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (47).$$

126. No material is capable of resisting successfully the shock of a freely moving body, unless possessing resilience equal in amount to the stored energy of the moving mass. Elasticity, combined with a wide range of flexibility and with great strength, gives maximum shock-resisting power. The resilience of timber makes it valuable as backing for armor-plate exposed to the impact of heavy shot.

Shapes such as permit distortion to occur throughout the greatest possible extent of material are best. Bolts and tie-rods exposed to shock should be given great length, and their minimum cross-section should extend throughout as much of their length as possible. Beams of uniform resistance to cross-breaking should be used if possible when impact is to be resisted. These are: if fixed at one end and loaded at the other, either of constant depth and triangular horizontal section, or of uniform thickness laterally, and of parabolic

form in the vertical plane; if uniformly loaded they are in the vertical plane, a pair of parabolas having a common vertex, and of uniform thickness, or they are triangular in horizontal section and of constant depth.

Beams of uniform strength are, if supported at the ends and loaded in the middle, in plan, a pair of triangles with common base at the loaded point and of uniform depth, or they are a pair of parabolas in vertical projection with uniform thickness. If uniformly loaded, they are, when of uniform depth, parabolic in plan, and when of uniform breadth are ellipses in the vertical plane.

The following table represents the *relative* amount of *work* required to twist off pieces of the material named, each piece having been turned down to a diameter of ⅞ inch (2.2 centimetres) as shown in Fig. 39.

FIG. 39.

The values given indicate the relative power of resistance to torsional rupture by shock.

White pine, taken as a standard, is represented by unity.

TABLE XXII.

RELATIVE TORSIONAL RESILIENCE.

NAME.	VALUE.	NAME.	VALUE.
White Pine.....	1.00	Yellow Pine.....	3.87
Spruce.....	1.50	Black Walnut.....	3.95
Red Cedar.....	1.61	Locust.....	5.80
Spanish Mahogany....	1.65	Oak.....	6.60
Ash.....	2.25	Hickory.....	6.90
Chestnut.....	2.40		

Thus oak, although not capable of resisting so high a torsional stress as either hickory or locust, or even good

Spanish mahogany, has great resilience, and is well fitted to resist shocks.

127. Strain Diagrams of Woods.—The accompanying diagrams exhibit graphically all the mechanical properties of the more important woods, as obtained by the use of the machine producing strain-diagrams automatically (Fig. 40).

It represents the results of average experiments made upon a considerable number of varieties of wood, the test-pieces of the form shown in Fig. 39 being used. The diameter of the neck of each piece was ⅞ of an inch (2.2 centimetres).

This size is convenient in consequence of the fact that the coefficient of ultimate strength for the standard diameter of one inch (2.54 centimetres) is obtained, with a close approximation to exactness, by simply multiplying the twisting moment for each piece by 1.5.

These curves exhibit the relative stiffness, strength, and resilience of the woods tested. The inclination from the vertical of the straight line, forming the first portion of each diagram, is a measure of stiffness; the height of the maximum ordinate indicates the ultimate strength; the point at which deviation from this straight line commences determines the limit of elasticity, and the area included within each diagram is proportional to the torsional resilience of the test-piece.

The fact that the commencement is, in each case, almost a perfectly straight line, as is well exhibited in the curve *a*, *a*, *a*, of locust, where the horizontal scale is purposely magnified, justifies the usual assumption that, up to the limit of elasticity, Hooke's law is correct, and that the angle of torsion is proportional to the twisting moment.

In most cases the torsional resistance increases with the total angle of torsion up to a maximum, then, passing the limit of elasticity, it drops off more or less rapidly, returning finally to zero. In the brittle woods the fall takes place suddenly, while in the tougher and more elastic varieties the resistance decreases very slowly, in some cases vanishing only after the test-piece has been twisted through a very large angle.

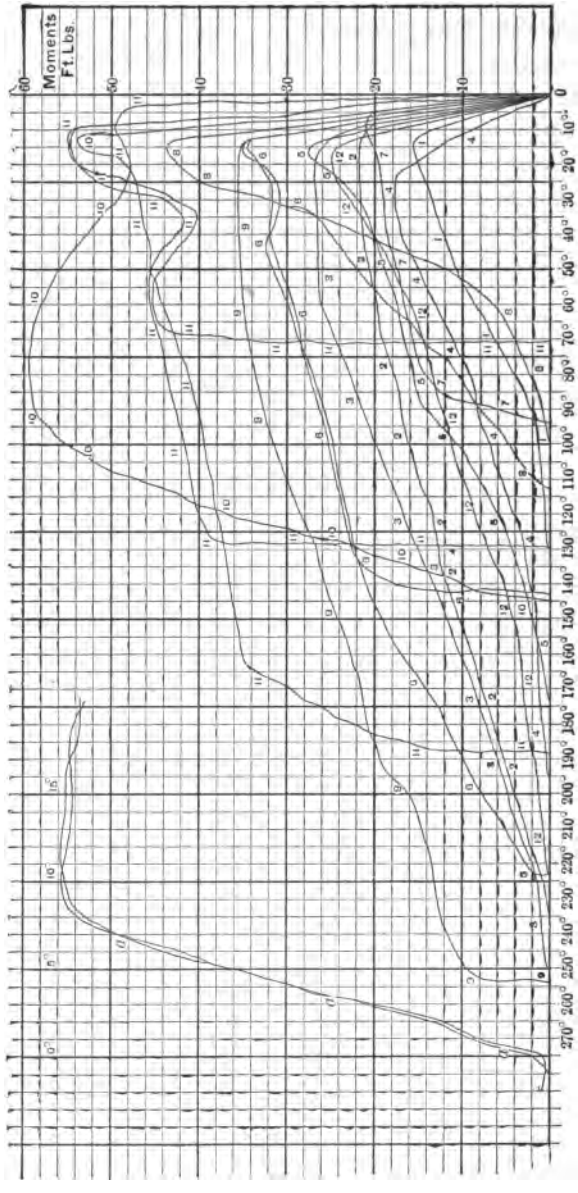

FIG. 40.—AUTOGRAPHIC STRAIN-DIAGRAMS OF WOODS. R. H. THURSTON.

In the case of black walnut, 6, 6, 6; locust, 11, 11, 11; and in a still more remarkable manner, in that of hickory, 10, 10, 10, a striking peculiarity is exhibited. In these curves the resistance increases with the amount of torsion until a maximum is reached; the line then drops to a point considerably below, and thence again *rises* and passes another maximum, which, in the case of hickory, is only reached after a torsion of 75°. The resisting moment then becomes considerably greater than at the limit of elasticity.

This is due to the fact that in those woods in which it is noticed, the lateral cohesion is much less in proportion to the longitudinal strength than in other varieties. In these examples the first maximum was passed at the instant when, the lateral cohesion of the fibres being overcome, they slipped upon each other, and the bundle of, then, loose fibres readily yielding the curve dropped until, by lateral crowding, further movement was checked and the resistance again rose until the second maximum was reached. Here yielding again commenced, this time by the breaking of the fibres under longitudinal stress—under that component of torsional stress which takes a direction parallel with that of the fibres in their new positions. In these cases rupture never occurs by true shearing in the transverse plane. The fibres part one after another, the exterior ones breaking first under a tensile stress.

128. Characteristics of Strain Diagrams.—The following varieties of wood were subjected to torsional fracture, and the curves obtained are shown in the plate (Fig. 40):

1. White Pine (*Pinus strobus*);
2. Yellow Pine (*Pinus australis*), sap-wood;
3. " " " " heart-wood,
4. Black Spruce (*Abies nigra*);
5. Ash (*Fraxinus Americana*);
6. Black Walnut (*Juglans nigra*);
7. Red Cedar (*Juniperis Virginianus*);
8. Spanish Mahogany (*Swietenia mahogani*);
9. White Oak (*Quercus alba*);
10. Hickory (*Juglans alba*);

11. Locust (*Robinia pseudacacia*);
12. Chestnut (*Castanea vesca*).

The curves exhibit the relative values of the materials tested, for the various purposes to which they may be applied.

White pine, 1, 1, 1, yields quite rapidly as the torsional moment increases, and the considerable inclination of the line from the vertical indicates its deficiency in stiffness. It soon reaches the limit of elasticity, and the diagram exhibits the maximum strength of the test-piece, 15½ foot-pounds (2.2 kilogrammme-metres). Passing the limit of elasticity and the maximum moment of resistance almost simultaneously, its resisting power decreases rapidly, and with tolerable uniformity,, until, at "a total angle of torsion" of 130°, it is twisted completely off. The area comprised within the curve is comparatively small and it is thus shown to have little resilience.

Yellow pine is found by an examination of its curve, 2, 2, 2; 3, 3, 3, to have much greater stiffness, strength, and resilience. The sap-wood, 2, 2, 2, is equally stiff in the examples tested, with the heart-wood, 3, 3, 3; but sooner passes its limit of elasticity.

Spruce, 4, 4, 4, 4, is less stiff than white pine, but possesses greater strength and resilience; its moment of resistance reaching 18 foot-pounds (2.5 kilogramme-metres), and twisting through a total angle of torsion of 200°.

Ash, 5, 5, 5, 5, seems to be weaker and less tough than is generally supposed; it is possible that the specimens tested were over-seasoned. Its most striking peculiarity is its rapid loss of strength after passing its limit of elasticity.

Black walnut, 6, 6, 6, 6, of the excellent quality and good condition as regards seasoning, of the samples tried, is very stiff, strong, and resilient, and is but little inferior to oak. Its resisting moment reaches 35 foot-pounds (4.84 kilogramme-metres), and one specimen reaches a total angle of torsion of 220°.

Red cedar, 7, 7, 7, 7, is stiff, but brittle, and loses all power of resistance after twisting through an angle of 92°. A tor-

sional moment of 20 foot-pounds only produces a total angle of torsion of 5° (2.76 kilogramme-metres).

Spanish mahogany, 8, 8, 8, 8, is very stiff and strong. It is deficient in toughness and resilience, losing its power of resistance very rapidly after passing the limit of elasticity.

White oak, 9, 9, 9, 9, has less torsional strength than either good mahogany, locust, or hickory; but is remarkable for its great toughness. It passes its limit of elasticity at 15°, but loses its resisting power very slowly indeed; we find the latter almost unimpaired until it has been subjected to a torsion of 70°; it only yielded completely at 253°.

Hickory, 10, 10, 10, 10, exhibits in its curve the pair of maxima already referred to, and has the highest ultimate torsional strength, combined with unusual stiffness and considerable resilience. Its moment of resistance to torsion reaches a maximum of 58 foot-pounds (8. kilogramme-metres).

Locust, 11, 11, 11, 11, has greater stiffness than any other wood in the list, and stands next to hickory in strength; it is, also, very resilient. Three diagrams are given, each of which possesses its own peculiarities. One specimen is twisted, only through a total angle of torsion of 4°, by a torsional moment of 48 foot-pounds (6.63 kilogramme-metres).

When more than one curve is given for the same wood, the stiffness and ultimate strength are usually very nearly equal, and the difference between the several specimens becomes marked, if at all, in their degree of toughness.

Determining relative stiffness by obtaining values of the ratio of twisting moment to the total angle of torsion, we obtain the following:

TABLE XXIII.

RELATIVE STIFFNESS OF WOODS.

1. White Pine	1.00	7. Red Cedar	4.00
2. Yellow Pine, sap	2.25	8. Spanish Mahogany	3.00
3. " " heart	2.25	9. Oak	2.53
4. Spruce	0.67	10. Hickory	4.15
5. Ash	1.87	11. Locust	5.50
6. Black Walnut	2.63	12. Chestnut	1.60

129. Wertheim on the Effects of Torsion.—The most

extended and delicate researches upon the laws of resistance to torsion were made by M. G. Wertheim.*

His most important conclusions were the following:

(1.) The torsion angle consists of two parts, one of which is temporary, the other permanent. The latter increases continually, but not regularly.

(2.) The temporary part increases more rapidly than the applied moment, up to the limit of elastic resistance, and, in some cases, beyond.

(3.) The temporary part does not precisely vary with the length twisted. The shorter the piece, the greater this disproportionality.

(4.) Torsion causes a diminution of volume in homogeneous substances, the density increasing from the centre to the circumference. The diminution is proportional to the product of the length of the piece, and the square of the angle of torsion.

These conclusions are deduced from experiments upon small angles of torsion.

130. Effect of Prolonged Stress upon the Strength and Elasticity of Pine Timber.†—Experiments made by Mr. Herman Haupt showed that timber may be injured by a prolonged stress far within that which leaves the material uninjured when the test is made in the usual way and occupies a few minutes only.‡ An extended series of experiments made intermittently in the Mechanical Laboratory of the Stevens Institute of Technology, Department of Engineering, included an examination of this subject, and the result has confirmed Haupt's earlier work, and has given a tolerably good idea of the effect of prolonged stress in modifying the primitive relation of stress and strain where the wood is good Southern yellow pine.

A selected yellow pine plank was obtained for test, the

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* *Annales de Chemie et de Physique*, vol. xxiii., 1st series, vol. l., 3d series.

† From the Proceedings of the American Association for the Advancement of Science, vol. xxx., Cincinnati Meeting, August, 1881. R. H. Thurston.

‡ Bridge Construction, N. Y., 1871, p. 61.

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history of which was known. The stick was cut at Jacksonville, Florida, in October, 1879, was received early in the following year, and was piled in the yard, air-seasoning, until taken for test in the spring of 1880. The plank measured 4 inches × 12 inches × 24 feet (10.16 × 30.48 × 731.52 centimetres). When tested, it had been seasoning six months, the latter part of the time indoors.

From the middle of this plank a stick was first cut 3 inches × 3 inches × 24 feet (7.62 × 7.62 × 731.5 centimetres), and from this was cut a set of ten pieces from 40 to 54 inches long (101.6 to 137.2 centimetres), and from 1¼ to 3 inches square in cross-section (3.16 to 7.62 centimetres) square. These latter pieces were tested under various conditions, as reported, to determine the values of their moduli of elasticity and rupture.

The moduli of rupture were usually 11,000 to 12,000 for the expression $R = \frac{3Pl}{2bd^2}$ (in metric measure, 773.3 to 843.6), and the moduli of elasticity ranged up to two and a quarter millions (in metric measure, $10^6 \times 1406$ to $158175 + 10^4$). In specific gravity the wood ranged from 0.75 to 1.00, usually about 0.85. When kiln-dried to a moderate extent, the density was but little altered, if at all, but the modulus of elasticity rose to two and a half millions pounds, nearly, and the modulus of rupture was increased about 20 per cent.

From the previously unused part of the plank a set of three test pieces was cut about one inch (2.54 centimetres) square in section, and tested on supports 40 inches (101.6 centimetres) apart, to determine their breaking loads. The result will be hereafter shown in detail. In these specimens the annual rings were in the cross-section of each piece, indicated by lines making angles of 45° with the edges. These pieces broke at 345, 380, and 410 pounds respectively. The weakest piece broke by splintering, and had it been as sound as the others would probably also have sustained a somewhat heavier load. As will be seen by comparison with the other and with subsequent tests, the deflection of the strongest piece in the set is exceptionally small, and the piece probably

exceptionally strong and stiff. We may, therefore, take 375 pounds (170 kilogrammes), or a trifle over, as a good average for loads breaking pieces of this size.

Nine other pieces were cut and dressed to the same size, and were mounted on supports 40 inches apart, in a frame arranged for the purpose in the workshop of the Institute, in three sets of three each. These sets were loaded thus:

1st set.....250 pounds (113.6 kilogrammes);
2d set.....300 pounds (136.4 kilogrammes);
3d set.....350 pounds (158.1 kilogrammes);

or to about 60, 80, and 95 per cent. of their probable maximum strength, as indicated by ordinary test of the companion lot above described. Their deflections were measured when set, and at intervals subsequently, by means of an accurate micrometer reading to ten-thousandths of an inch.

131. **Results of Tests.**—The whole set of bars, loaded most heavily as above, broke within two days; one bar yielding at the end of a period included between observations taken at 4½ and 13½ hours from the beginning, the second breaking at some time between 27 and 30½ hours, and the third giving way at the end of 43 hours. A load of 87½ per cent., the maximum obtained by usual methods of tests, is thus shown to be capable of breaking the piece under the conditions here described, and an apparent "factor of safety" of 1¼ is evidently not a factor of safety at all when time is given for the piece to yield.

The second set, loaded with 0.75 the maximum momentary weight, all broke, one at the end of about 3½ days, another after 5 days, and the third at the end of a little more than a month. It is probable that these differences of time are due to differences of strength more than to variations of the effect of time of stress. A "factor of safety" of 1⅓ is evidently not a real factor of safety for wood in such cases as this.

The third and last set of test pieces were loaded with 60 per cent. of the average breaking weight under ordinary test. Left under this load, the deflection, in every instance, slowly and steadiiy increased from about one inch (2.54 centimetres)

to some considerably larger amount at the end of the period of investigation. Fortunately, as is indicated by a comparison of these initial deflections with those observed under the same weights when testing the first set, and by their close accordance with each other, these pieces are all good samples of a good quality of yellow pine.

The increase of deflection was almost precisely the same for all for several months, a fact which is of importance, as showing not only the gradual progress and steadiness of yielding, but also that no accident produced the final rupture. Finally, after several months (about 6,000 hours; the exact time is uncertain), the piece which had at the beginning shown most pliability broke completely down. The next piece to break was that which was intermediate in stiffness between the two others; it broke at the end of about 9,000 hours—precisely one year from the date on which the load was imposed. The last piece of this set still carried its load of 60 per cent. of the maximum under ordinary test at the last date, but it was still very slowly but unmistakably yielding, its deflection having increased nearly 0.4 inch (1.016 centimetres) during the preceding five months. *It finally broke July* 31, 1881, *about* 11,100 *hours after it received its load* (15 *months*), which load was, it will be noted, but about 60 per cent. of its estimated—and probably practically correct—original breaking weight.*

An inspection of the broken bars gave no indication of reduction of strength by decay; the pieces were perfectly sound and strong, and the fractures showed excellent material.†

132. Comparison of Results.—Comparing the ultimate deflections attained by the several sets of bars, it was found that the average under ordinary test was about 1.8 inches (4.6 centimetres). Under a load of 0.95, that then carried, the rods broke at a deflection of 2.4 inches (6 centimetres); loaded to .80, the maximum, the deflection became, at the end, 3 inches (7.62 centimetres) as a maximum, and the ultimate de-

* Investigation conducted by J. E. Denton; observer, A. R. Riesenberger.

† Subsequent tests (1882) by the author, of several pieces of the broken bars confirmed this conclusion fully.

flection of the most lightly loaded pieces (70 per cent. the maximum load) was something less.

The last set being compared with the first, it is concluded that a load of 60 per cent., the maximum given by the usual form of test, is for such pieces unsafe, although it would seem that a slightly smaller load might have been carried indefinitely, or until decay should weaken the timber. A factor of safety of two would possibly have permitted indefinite endurance under static load.

Taking the probable breaking load under unintermitted stress as 50 per cent., that sustained as a maximum under usual tests, and *then* applying a factor of safety of two, we obtain a safe factor, based on the ordinary test, 4.

133. Conclusions.—In brief, the conclusions to be drawn from the research here described, are evidently that small sections of yellow pine timber yield steadily over long periods of time under loads exceeding 60 per cent., the maximum obtained by ordinary tests of their transverse strength, and finally break after a period, which with the lighter loads may exceed a year; that deflections half the maximum reached under test may be unsafe for long periods of time, and that a factor of safety of at least 4 should be used for permanent static loads when the character of the material is known.

The author would, in the light of what is now known, always use a factor of safety of at least 5 under absolutely static loads, and when the uncertainties of ordinary practice as to the exact character of material, and especially where shake and the impact of live loads were to be considered, would make the factor not less than 8, and for much of our ordinary work 10.

134. Conclusions relative to the application of Wood in Engineering Construction.—From what has been already learned, and by comparison with that which is hereafter stated concerning other materials used in engineering, some conclusions may now be deduced, relative to the value of wood to resist the various kinds of stress which the engineer is compelled to meet in his constructions, and for special applications.

For pattern-making a light wood is generally desired, capable of seasoning without checking, and of being easily worked. For large patterns, white pine or cherry is generally used; and for small patterns, where weight is less objectionable, and where strength, smoothness of grain, and firmness of texture are more essential, mahogany is taken. For extremely small patterns, boxwood and ebony are much used.

For turned work, alder, beech, birch, and white pine are used when an easily worked wood is desired; for a tough and fine-grained, clean and smooth-working material, holly is unexcelled; it requires, however, great care in seasoning. Apple, maple, pear, locust, boxwood, ebony, oak, and elm are all valuable for lathe work.

Black walnut, mahogany, and rosewood are used for ornamental purposes, and work well in the lathe as well as at the bench.

For ordinary joiner's work, the pines are principally used, and for finer work, maple, black walnut, and mahogany are in request.

Rosewood and some other tropical woods are generally used only for expensive work, such as is never necessary for the engineer to construct.

Where extreme lightness is desired, white pine is generally used; for purposes requiring a wood both light and strong, yellow pine is most called for.

135. **Woods of Commercial Value** in connection with properties usual or peculiar as named at their heads respectively, are as follows:

Elasticity.—Ash, hickory, hazel, lancewood, chestnut (small), yew, snakewood.

Elasticity and Toughness.—Oak, beech, elm, lignum-vitæ, walnut, hornbeam.

Even Grain (for carving and engraving).—Pear, pine, box, lime-tree.

Durability (in dry works).—Cedar, oak, poplar, yellow pine, chestnut.

Wet Construction (as piles, foundations, flumes, etc.).—Elm, alder, beech, oak, plane tree, white cedar.

Ship-building.—Cedar, pines (deals), firs, larches, elms, oaks, locust, teak.

House-building.—Pines, oak, white wood, chestnut, ash, spruce, sycamore.

Furniture.—Common: beech, birch, cedars, cherry, pines, white wood. Best furniture: amboyna, black ebony, mahogany, cherry, maple, walnut, oak, rosewood, satinwood, sandalwood, chestnut, cedar, tulipwood, zebra wood, ebony.

Machinery and Millwork.—Frames: ash, beech, birch, pine, elm, oak. Rollers, etc.: box, lignum-vitæ, mahogany. Teeth of wheels: crab-tree, hornbeam, locust, hickory, and maple. Foundry patterns: alder, pine, mahogany.

Of the above-named varieties, those that chiefly enter into commerce in this country are oak, hickory, ash, elm, cedar, black walnut, maple, cherry, butternut, white wood, etc. No approximate figures even can be given of the amount annually used in this country.

In parts requiring great strength and toughness, white oak, hickory, and locust are used.

The first named is used for water-wheels, shafts, for places where lignum-vitæ cannot be used, for subaqueous bearings —as for steps for turbine wheels—and for any position in which it will be kept constantly wet.

Hickory and white oak are particularly well adapted for teeth of mortice-gear wheels, as are also maple and beech; and the former for any dry situations in which their great strength and toughness are likely to be found requisite. Locust is selected where strength and toughness are desired, and where large pieces are not necessary. The last five woods, and maple and the pines, are those most frequently used by the mechanical engineer.

In the drawing office, boxwood, holly, and red cedar are used for the blades of *T*-squares, and for rulers, and scales. Some of the ornamental woods are used for the heads of *T*-squares.

Pearwood is found to be well adapted for model work, and maple for general light work requiring a good surface.

The latter makes good teeth for mortice wheels which are

not subjected to very heavy stress. Sour applewood is even better for the latter purpose, and is much sought by wheelwrights for gearing used in dry situations. In presence of moisture, white oak is the best of all woods for this work. When wood is required in carpentry, for floor-joists and rafters, the stiff woods are selected; for carriage-shafts and poles, builders select the toughest woods, while for tie-beams, those woods having greatest lateral cohesion and tensile strength are taken. In building railroad cars, where lightness and strength should be well combined, pine is preferred above all other woods.

Tough and cross-grained woods are most difficult, and therefore most expensive to work; the most brittle woods are usually easily worked, the fine-grained woods take the smoothest polish, and the surface is best preserved by the harder varieties.

136. **The Figure of the Markings of Wood** depends more upon the particular directions of the fibres than upon any difference of color. If a tree were formed of cylindrical layers, the horizontal section would exhibit concentric circles, the vertical section giving parallel straight lines; and the oblique section, ellipses. But few trees are to be found exactly straight, and, therefore, although the three sections have a general tendency to exhibit the figures described, every bend and twist in the tree disturbs the regularity of its fibre, and adds to the variety of grain and ornamentation of the wood. A perpendicular cut through the heart of the tree exhibits the most diversified surface, because in it occurs the most profuse mixture of the fibre, the oldest and newest being presented in the same plank.

Curls are formed by the confused filling in of the space between the forks of the branches. The figures thus produced cause a log to be valuable in proportion to the number of curls it contains.

Figures are also produced in the following manner. The germs of the primary branches are set at an early period of the growth of the parent stem, and thus give rise to knots. But many fail to penetrate to the exterior, and are covered

over by later annual rings. When the germ forces its way to the surface, the fibres of the trunk bend aside when they encounter the knot, and in the soft woods do not unite with it. The hardness of knots is due to the close grouping of the fibres, and to their compression by the surrounding wood, which itself is allowed to expand by the yielding of the bark.

The same operation goes on in the roots of trees, and furniture veneers are often obtained from them. The bird's-eye maple has points or spines on the inside of the bark, which penetrate the wood and make irregular indentations. These cause that peculiar appearance from which the wood takes its name.

In woods, the figure of which resembles the ripple-marks of the sea on fine sand, such as satinwood, sycamore, mahogany, and ash, the figure is produced by the serpentine form of the grain. The fibres of all such pieces are wavy in planes at right angles to that on which the ripple is observed, if not on both, those parts of the wood which receive the light being brightest.

Woods having silver grain, or marked medullary rays, exhibit a dappled appearance similar to that produced on silk by threads crossing one another. English oak, Riga and Dutch wainscot logs, Austrian wainscot, etc., have this peculiarity. In the oak plank the principal lines are the edges of the annual rings, which show parallel lines.

Damask pencillings, or broad, curly veins and stripes, are caused by groups of the medullary rays which undulate from the surface to the centre of the tree, and creep in betwixt the longitudinal fibres. Were the fibres of trees arranged with the uniformity and exactitude of a piece of plain cloth, they would show an even, uninterrupted color; but being arranged in irregular, curved lines, every section partly removes some and exposes others, thus producing a great variety of figure.

137. Coloring of Woods.—Some woods are nearly uniform in color, and some have several shades of the same hue or of several colors. In the transverse section of such woods the tree seems to have clothed itself with different coats of

various colors. Tulipwood, kingwood, zebrawood, and rosewood illustrate this case. In ordinary planks these markings are drawn out into stripes, bands, and patches, or wavy figures of beautiful or grotesque form.

Woods variegated both in grain and color are generally employed for objects with smooth surfaces, as in cabinet-work. Such are Amboyna, kingwood, mahogany, maple, partridge, rose, satin, snake, tulip, and zebrawood. Specimens of marquetry often beautifully illustrate the use of such wood for the purpose of ornamentation. The same style of work in mouldings has an inferior effect.

The colors of "fancy woods" are not usually liable to fade by exposure to light, tulipwood being one exception; but age darkens them and mellows the general effect. Only the whitest of varnishes should be laid over them, for the natural tint will easily be spoiled. The rich *greenish* brown of walnut is esteemed for piano-forte cases, for which work, however, rosewood has hitherto been more generally used. The rich, deep orange of Spanish mahogany makes beautiful tables and counter-tops, and the size of the timber adapts it to either use. Honduras mahogany, of a brownish tint, is used for all kinds of superior cabinet-work, while oak is principally employed where durability is a necessity. Pitch-pine is pleasing in color and figure. Rosewood has very rich tints, and is much used.

138. Carpentry is the art of construction in wood, and properly includes several divisions as joinery, cabinet-making, pattern-making, and ship-construction. The engineer will find special treatises on each subject which will give full information relating to trade methods. In this place only the simplest principles involved in all wood-working can be given.

The fashioning of wood is often done by machinery, and hand labor is only employed in fitting and in forming special shapes or in making constructions which are not called for in such quantities as to justify the building of special machinery for their manufacture.

In constructions of wood the parts are usually straight and simply formed pieces, and stresses are almost invariably

taken either as transverse loads or by compression; wood is unfitted for sustaining tensile forces, as it is extremely difficult to obtain such a secure hold upon the material as to permit the tenacity of the piece to be fully brought into play before fracture occurs by detrusion.

In uniting timber it is advisable to be exceedingly careful to reduce the loss of section by cutting for the joints and fastening to a minimum; to take advantage of peculiarities in the "lay" of the grain wherever possible; to make surfaces exposed to pressure of such shape, and to place them in such a position that the lines of pressure shall be normal to them; to give ample area of bearing surface to insure safety against injury by the maximum stress anticipated; to fit abutting parts perfectly and unite them securely, and to insure, wherever possible, equal strength in the pieces and their fastenings, except in places where it is found advisable to make some one point somewhat weaker than the others in order that, in case of accidental rupture, the most costly piece shall be saved at the expense of one that can be better spared. Precaution is necessary to prevent the use of such fastenings, or so locating them that they shall either cut through the wood or crush their bearings. The joints should be simple in form and carefully designed for each case.

139. Joints receiving compressive stresses are usually made by cutting squarely across the line of pressure; but those made to resist either transverse or tensile forces are less simple.

Scarfing is the most usual method, and practical in several ways, as is seen in the accompanying sketches:*

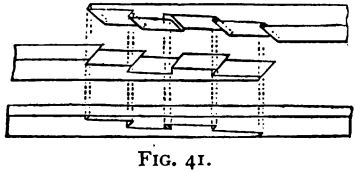

FIG. 41.

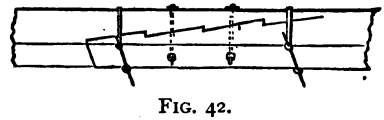

FIG. 42.

In the examples, Figs. 41 and 42, the pieces to be joined

* See Appletons' Cyclopædia of Applied Mechanics.

are cut diagonally at the abutting ends and a stepped surface formed on each side in such a manner that, being fitted and bolted together as shown, the joint becomes nearly as strong as the solid wood; to obtain still greater strength of joint the upper and lower surfaces of the scarf are sometimes covered by a pair of "fish-plates" of boiler-iron extending some distance each way beyond the joint and bolted on by through-bolts having their heads bearing on one plate and their nuts on the other.

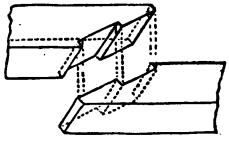

FIG. 43.

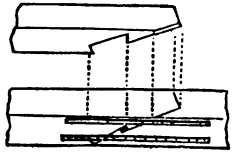

FIG. 44.

In other cases joints are made as in Figs. 43, 44, above, and the lap observed in the second sketch is brought to a bearing by a key of hard wood driven into place after the parts are fitted together, as is also seen in Fig. 41.

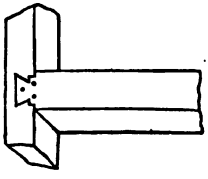

FIG. 45.

Pieces brought together at right angles are often dovetailed as in Fig. 45.

For other cases, tenons, or the end of one piece fitting into mortices, cut through the bearing surface as in the sketches below, are adopted, and when the tenon enters at such an inclination as

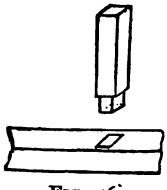

FIG. 46.

FIG. 47.

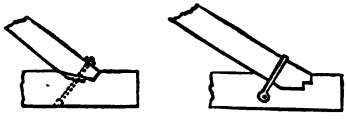

FIG. 48.

to give rise to danger of slipping under the load or splitting out, the use of a bolt or a strap, as shown, will give security.

King-posts are united with diagonal, as with rafters

(Fig. 49), with braces and tie-beams (Fig. 50), as here shown, and straps or bolts are often added for greater safety. The vertical and one diagonal may be united as in Fig. 51.

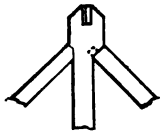

FIG. 49.

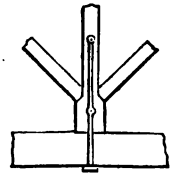

FIG. 50.

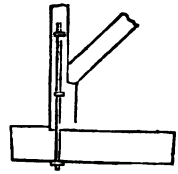

FIG. 51.

The bridge-work timber verticals and diagonals often rest on cast-iron shoes which have a broad bearing on the chords, and thus give security against crushing; this is also practised in the construction of heavy wooden roof-frames.

Timbers crossing each other are often halved together or are lapped when simply abutting. The length of scarf or other joints must be such that the total resistance to detrusion shall be at least equal to the resistance to transverse rupture; the hard woods, as oak, hickory, ash, elm, locust, are usually scarfed to a length equal to six times their depth; pine and other soft woods are given twice as long a scarf.

Wooden girders should have good bearings at the ends, and should rest on the solid wall and have a bearing on stone or iron, with ample space for circulation of air.

140. Pins used in securing parts of timber-work are often made of wood and are called "treenails"; their diameter is usually about one-third the thickness of the planks which they unite; they are best made of oak or locust, and may be taken as having a strength of 3,000 to 4,000 pounds per square inch (210 to 280 kilogrammes per square centimetre) of cross-section.

Nails are used in small and spikes in large sections of wood-work, and are given a length of from two to three times the thickness of the thinner of the two parts united by them. The following table from Bevan's experiments shows the relative value of several standard sizes:*

* Tredgold: Carpentry.

TABLE XXIV.

HOLDING POWER OF NAILS.

KIND.	LENGTH.		NO. PER		DEPTH DRIVEN.		RESIST. TO DRAWING.	
	In.	Cm.	Lb.	Kilogs.	In.	Cm.	Lbs.	Kilogs.
Brads.....	0.44	1.12	4,560	10,000	0.4	1.00	22	48.4
Brads.....	0.53	1.35	3,200	7,040	0 44	1.12	37	81.4
Brads.....	1.25	3.18	618	1,360	0.50	1.27	58	127.6
Fivepenny.	2.00	5.08	139	306	1.50	4.81	320	740.0
Sixpenny..	2.50	6.35	73	160	1.00	4.54	187	411.4
Sixpenny..	2.50	6.35	73	160	1.50	4.81	327	719.4
Sixpenny..	2.50	6.35	73	160	2.00	5.08	530	1,166.0

The weight of nails is often roughly taken as about $W = 2l^3$ when W is weight in pounds per 1,000, and l their length in inches; in metric measure $W = 0.14l^2$ for kilogrammes and centimetres. The resistance to a drawing force varies as roughly as $d^{\frac{3}{2}}$, when d is the depth to which the nail is driven. Bevan found the following to be the resistance of a sixpenny nail driven 1 inch (2.54 centimetres) into different woods:

	LBS.	KGS.		LBS.	KGS.
Pine, across grain.....	187	411.4	Pine, with grain.....	87	191.4
Oak.....	507	1,115.4	Elm, " "	257	565.4
Elm.	327	829.4			

The resistance to driving by steady pressure is, in soft woods, 20 per cent. greater than resistance to extraction. A sixpenny nail forced into Christiania "deal" offered resistance as below:

DEPTH.	Inches.....	0.25	0.5	1.	1.5	2.
	Centimetres.....	0.64	1.77	2.54	3.81	5.08
PRESSURE.	Lbs.....	24	76	235	400	610
	Kilogs.....	11	34.5	107	171	276

Wellington* found the resistance of railroad spikes driven into various woods to be:

WOOD.	DRIVING IN.		PULLING OUT.		WOOD.	DRIVING IN.		PULLING OUT.	
	Lbs.	Kgs.	Lbs.	Kgs.		Lbs.	Kgs.	Lbs.	Kgs.
Beech.....	6,743	3,074	5,978	2,717	Oak, green.....	5,820	452.6	6,523	2,965
Ash.....	5,953	2,750	4,560	2,074	" seasoned...	6,433	2,924	4,281	1,946
Elm.....	4,606	2,094	3,690	1,580	Chestnut.....	3,691	1,580	3,260	1,936
Maple.....	3,843	1,746	3,111	1,323	Hemlock.....	2,100	1,323	1,996	907

It was found that elm and ash will hold a spike about two-thirds as well as oak or beech, and a third better than chestnut; soft maple and sycamore are four-fifths as effective as chestnut, two-fifths as good as oak and beech, and a half better than hemlock.

Wood-screws are used wherever the parts are to be again separated; where the stresses are likely to be greater than can be safely resisted by nails; where the pieces joined are liable to be split or otherwise injured by the use of nails, or where nicety of fitting is important. Their resistance is nearly as the square of their diameters, if made of such length that their full strength may be utilized; shorter screws, or any screws that pull out without breaking, resist merely as the area fractured, *i. e.*, about as the product of the length of screw holding in the wood and diameter outside of thread. Bevan pulled screws 0.22 inch (0.5 centimetre) in diameter over the thread, having twelve threads per inch (5 to the centimetre), from a depth of a half inch (1.27 centimetre), thus:

Beech.....	460 to 990 lbs. 210 " 450 kgs.	Mahogany	770 lbs. 350 kgs.
Ash.....	790 lbs. 360 kgs.	Elm.....	665 lbs. 300 kgs.
Oak.....	760 lbs. 345 kgs.	Sycamore	830 lbs. 377 kgs.

* *Railroad Gazette*, No. 51, p. 668.

TABLE XXV.

HOLDING POWER OF SCREWS.

LENGTH.		NUMBER.								
Of screw in inches.	Of thread on screw. Inches.	Common number of screw.	Threads to 1 inch.	Threads to 1 cm.	Distance screwed into wood. Cm.	Average resistance. Kilogrammes.	Distance screwed into wood. Inches.	Average resistance. Pounds.		Relative resistance. Taking resistance of 1½ in. screw = 943 as 1.
3	1¾	20	8	3.2	6.4	1312	2½	2886	Fine grain dry white ash.	3.06
								2424	Coarse grain dry white ash.	2.57
3	1¾	20	8	3.2	6.4	1102	2½	2879	Black walnut.	3.05
2½	1¾	16	9	3.6	5.1	1217	2	1857	Coarse grain dry white ash.	1.97
2½	1¾	14	10	4.0	5.1	844	2	1813	" " "	1.92
2	1¾	20	8	3.2	3.8	824	1½	1586	" " "	1.69
2	1¾	16	9	3.6	3.8	721	1½	1633	" " "	1.73
2	1¾	14	10	4.0	3.8	733	1½	1580	" " "	1.67
2	1¾	12	12	4.8	3.8	709	1½	1549	" " "	1.64
1½	⅞	16	9	3.6	2.5	519	1	1142	" " "	1.21
1½	⅞	14	10	4.0	2.5	538	1	1185	" " "	1.25
1½	⅞	10	13	5.1	2.5	438	1	943	" " "	1.00

When bolts and nuts are used, the wood should be protected by giving their heads and nuts a broad bearing on washers, 1½ to 2 times the diameter of the head for hard and soft woods respectively.

Iron fastenings should be avoided where the wood has an acid sap, as do some oaks. The sap of teak and of the pines protect iron fastenings. Where used they should be protected by paint, oil, or coal-tar, or by galvanizing.

141. Glues.—*Common Glue.*—The absolute strength of a well-glued joint is given as:

TABLE XXVI.

HOLDING POWER OF GLUE.

	POUNDS PER SQ. IN.		KILOS. PER SQ. CM.	
	Across the grain, end to end.	With the grain.	Across the grain, end to end.	With the grain.
Beech.....	2,133	1,095	149.31	76.65
Elm.....	1,436	1,124	100.52	78.68
Oak.....	1,735	568	121.45	39.76
White wood....	31.49	341	104.54	23.87
Maple	1,422	896	99.51	62.72

It is customary to use from one-sixth to one-tenth of the above values to calculate the resistance which surfaces joined with glue can permanently sustain with safety. A little powdered chalk strengthens glue.

Marine Glue.—India-rubber, 1 part; coal-tar naphtha, 8 to 12 parts; shellac, 15 to 20 parts; melted together. Use hot.

Glue dissolved in skimmed milk will resist the action of moisture; also glue softened with boiled oil or resin, and one-fourth its weight of iron oxide added.

Water-proof Glue.—Boil eight parts of common glue with about thirty parts of water, until a strong solution is obtained; add four and a half parts of boiled linseed-oil, and let the mixture boil two or three minutes, stirring it constantly.

142. Preservation of Timber.—The causes of decay in timber have already been stated (Art. 86), and the process of decay has been described.

As has been seen, timber should be protected against the deleterious effects of moisture and oxidation, and the attacks of insects. Timber lasts longest either in perfectly dry and well-ventilated places, or where it is kept constantly immersed in water. The problem of preserving timber from decay is fully stated when it is said that the object to be attained is the prevention of oxidation.

Timber which has been thoroughly seasoned by the methods already described, and which is perfectly dry, may be preserved by external applications. Under other circumstances, internal application of various solutions must be resorted to.

143. Paints and Varnishes are used for the protection and preservation of timber by external treatment. They form a coating upon the surface, which resists the wearing action of the weather, and prevents the entrance into the pores of the wood of either moisture or corroding gases.

Should the wood not have been previously well seasoned, however, paint only hastens decay by confining the moisture and hastening the fermentation of the putrescible matter remaining in the wood.

The following are among the best of this class of preserva-

tive compositions; many of them are recommended in the U. S. Army Ordnance Manual.

The proportions are given for 100 parts by weight of prepared colors, when not otherwise designated.

One gallon (3.79 litres)			of linseed oil weighs..	7.5	pounds	3.41	kgms.
"	"	"	spirits of turpentine..	7.25	"	3.3	"
"	"	"	Japan varnish	7.	"	3.18	"
"	"	"	sperm oil.....	7.12	"	3.23	"
"	"	"	neat's-foot oil.....	7.63	"	3.45	"

BOILED OIL.

Raw linseed oil	103.
Copperas	3.15
Litharge	6.3

Suspend the copperas and litharge in a cloth bag in the middle of the kettle of oil. Boil 4½ hours with a slow steady fire.

DRYER OR DRYING.

Copperas and litharge from the boiled oil	60
Spirits of turpentine	56
Boiled oil	2

The mixture from the boiled oil to be ground and thoroughly mixed with the turpentine and oil.

PUTTY. (FOR FILLING CRACKS.)

Spanish whiting, ground	81.6
Boiled oil	20.4

Make into a stiff paste. If not intended for immediate use, raw oil should be used; putty made with boiled oil hardens quickly.

Also, mix finely sifted oak or other sawdust with linseed oil which has been boiled until it has become glutinous.

WHITE PAINT.

	For inside work.	For outside work.
White lead in oil	80.0	80.
Boiled oil	14.5	9.
Raw oil	0.0	9.
Spirits turpentine	8.0	4.

Grind the lead in the oil, then add the spirits of turpentine.

For woodwork use 1 pound to the square yard for three coats (2.75 kilogrammes per square metre).

LEAD COLOR.

White lead in oil	75.0
Lampblack	1.0
Boiled linseed oil	23.0
Litharge	0.5
Japan varnish	0.5
Spirits turpentine	2.5

Grind the lampblack and litharge separately in oil, then stir into the white lead and oil. Turpentine and varnish are added as the paint is required for use, or when packed in kegs for transportation.

BLACK PAINT.

Boiled linseed oil	73.
Lampblack	28.
Litharge	1.
Japan varnish	1.
Spirits turpentine	1.

Grind the lampblack in oil; mix it with the other oil, then grind the litharge in oil and add it, stirring well. The varnish and turpentine are added last. This paint can be used for iron work.

GRAY OR STONE COLOR, FOR BUILDINGS.

	1st Coat.	2d Coat.
White lead in oil	78.0	100.
Boiled oil	9.5	20.
Raw oil	9.5	20.
Spirits turpentine	3.0	0.
Turkey umber	0.5	0.
Lampblack	0.25	0.25
Yellow ochre	0.00	3.

Mix like the lead color.

A square yard of new brickwork requires, for two coats, 1⅛ lbs.; for three coats 1½ lbs. In metric measures, one square metre requires for two coats .61 kilogrammes; for three coats .81 kilogrammes.

CREAM COLOR, FOR BUILDINGS.

	1st Coat.	2d Coat.
White lead, in oil	66.66	70.00
French yellow	3.33	3.33
Japan varnish	1.33	1.33
Raw oil	28.00	24.5
Spirits turpentine	2.25	2.25

A square yard of new brickwork requires for first coat ¾; for second ⅜ pounds; in metric measures, one square metre requires for first coat .4; for second .2 kilogrammes.

BLACK STAIN, FOR WOOD.

Copperas	1 lb.	.67 kgm.
Nutgalls	1 "	.67 "
Sal ammoniac	.25 "	.17 "
Vinegar	1 gall.	3.79 litres.

Stir occasionally, and it becomes ready for use in a few hours.

Clean and smooth the surface, filling the cracks with black putty, allowing it to harden. Apply the stain two or three times, then leave it a day or two to dry; finally rub with boiled oil until polished.

JAPAN VARNISH.

Litharge	4 lbs.	1.8 kgms.
Boiled oil	88 "	40.0 "
Spirits turpentine	2 "	.9 "
Red lead	6 "	2.7 "
Umber	1 "	.45 "
Gum shellac	8 "	3.6 "
Sugar of lead	2 "	.9 "
White vitriol	1 "	.45 "

Boil over a slow charcoal fire five hours, mixing all the ingredients except the turpentine and a small portion of the oil; the latter is added as required to check ebullition. The mixture must be continually stirred with a wooden spatula, and great care is required to prevent it taking fire.

The turpentine is added when the varnish is nearly cool, and should be well stirred in. The varnish must be put in close cans and kept tightly corked.

Japan varnish may be purchased.

Paraffin Paint.—Mix together good asphalt and paraffin in equal parts, melt, and stir well together. Add a small quantity of finely ground caustic lime, constantly stirring. Apply with a large brush. When this first coat has cooled, put on another coating of pure melted paraffin applied quickly and evenly.

Brown mineral (iron oxide) *paints*, as sold ready for mixing with oil, a paint of "red lead" and oil, or of "zinc white," are all used extensively on iron and for outside work.

Wood work exposed to the weather is repainted, in our climate, at intervals of four or five years.

The woodwork supporting the floors of bridges, and timber in damp situations as in wheel-pits, is sometimes coated with *coal-tar* prepared for use by boiling, and by the addition of a small quantity of chalk to give it body. This is also an excellent application for water-pipes, for smoke-stacks of iron, and other out-of-door ironwork. As a preservative against decay it is also excellent on woodwork, but is often seriously objectionable because of its inflammability. Boiling linseed oil, pitch and vegetable tar, applied hot, are not unfrequently used as external applications, and are found to be very effective preservatives. The soot from bituminous coal, mixed with oil or with coal-tar, is a very durable and excellent preservative, shedding water well, and protecting efficiently against oxidation. Fish-oil may also be used in some cases for a similar purpose. *Sulphate of iron*, in oil, has also been found to make a useful paint.

The materials which enter into the composition of paint frequently exert a decisive effect upon its preservative qualities. Adulterated and impure paints may not only lack preservative qualities, but may, by their adulterations, actually hasten decay. The most important constituent of paint is *White Lead*, which should be of good quality, and unmixed with any substances which impair its brightness. Its usual adulterations are chalk and the sulphates of lead and baryta; the latter is the least objectionable.

Zinc White is more expensive, and forms a better basis

than white lead; it, however, works dry under the brush and takes longer in drying; it does not have the covering properties of white lead, but forms, however, a more dense coating, which resists the action of the weather and retains its color better than lead paint. It is frequently adulterated with sulphate of baryta.

Red Lead makes a very durable paint and dries well.

Linseed Oil is one of the most important constituents of paint; it improves greatly by age, and ought to be kept at least six months before using. It can be made a "dryer" by boiling, or by the addition of foreign substances. It dries better than any other oil, has a heavy body, and it is owing to this fact that it is capable of resisting the action of the weather. Pure linseed oil is of a pale, transparent, amber color, very limpid, and has little odor, is comparatively sweet to the taste, and when exposed to the light and air grows lighter in color. In adulterated linseed oil the opposite effect takes place.

Nut Oil and *Poppy Oil* are inferior in quality to linseed oil, and are used to adulterate the latter.

Of the colors, yellow ochre is used as a body color more extensively than any other—the best is very durable in color. Amber, Vandyke, and metallic browns are derived from the iron salts, and are also very durable; they adhere to iron better, and are less affected by the air than the red lead.

The real value of any paint depends upon the quality of materials used in composition, and upon the care used in its mixing and preparation.

144. Charring the surface of well-seasoned timber is found to considerably increase its durability, and this is the method most frequently adopted for the preservation of those portions of fence posts which are buried in the ground.

An external application of *silicate of sodium* has been advised by Abel, for seasoned timber. It is said to form a hard and very durable coating upon the surface, and to act effectively as a preservative against fire, as well as against decay. The solution is laid on with alternate coats of lime wash. Two or three applications of the silicate of sodium

are required to form each coat. Sulphates of iron and of copper, the chloride of mercury, common salt, and other solutions, are occasionally used for external washes.

The common oil paints are, by far, the most usually applied. Their durability is increased by sprinkling liberally with sand, where circumstances permit.

In timber protected by external treatment, special care is required to fill cracks.

145. The Saturation of Timber, either seasoned or unseasoned, with antiseptic materials has become a matter of such great importance as to have attracted much attention. Many processes have been tried and recommended, but none are generally used in this country, and very few are practiced at all.

A few seem to be effective, but costly; many are of temporary benefit; others, while seeming to be useful at first, are actually injurious, ultimately destroying the timber which they are intended to preserve.

The external applications above described are of no value in defending the timber against the attacks of wood-boring insects. Sheathing the timber in metal, and one or two methods of saturation, are apparently the only reliable expedients.

Of the processes of preservation of wood by saturation, Kyan's consists in the injection of the *bichloride of mercury* (corrosive sublimate); Burnett used the *chloride of zinc;* Boucherie employed the *pyrolignite of iron;* Margery used the *sulphate of copper;* Bethell saturated his timber with *creosote*, or "dead oil," from gas works; Beer used a solution of borax.

The metallic salts owe their antiseptic property to the fact that they produce coagulation of the albumen, which is the fermentable and perishable part of timber.

The use of metallic salts was proposed nearly a hundred years ago, but the first practical applications were made about a half century ago.

146. "Kyanizing" was suggested by Sir Humphry Davy, some ten years before the process was patented by Sir R. H. Kyan, in England, in 1832.

The solution used consisted of one pound of the bichloride of mercury in four gallons (1 kilogramme to 33½ litres) of water. Timber thoroughly impregnated with the salt has great durability, but the general adoption of this process is precluded by the cost of materials. A hundred parts of timber absorbed one and a half parts of corrosive sublimate. Where it is brought in contact with iron it produces corrosion, and its application is thus rendered still less frequently permissible.

Kyanized timber was used to some extent in Great Britain and the United States when first proposed.

Among other constructions of timber thus prepared may be mentioned the aqueduct of the Alexandria Canal, crossing the Potomac River at Georgetown.

147. "Burnettizing" was proposed by Sir Wm. Burnett, in 1838, and has been quite largely practiced for special purposes.

The chloride of zinc, in the proportion of one part dissolved in ten parts of water, is forced into the pores of the wood under a pressure of from one hundred to one hundred and twenty-five pounds to the square inch (7 to 8.75 kilogrammes per square centimetre). Burnett's method was, originally, simple immersion in the solution two or three weeks.

An establishment was organized at Lowell, Mass., in 1856, in which burnettizing under pressure was practiced. Subsequently several railroad companies adopted this method and process, and erected burnettizing works.

The cost of preserving timber by this method, including interest on capital and all other expenses, ranged from five to seven dollars per thousand feet, board measure.

The process is not, however, believed to afford as perfect protection as the more expensive method of kyanizing.

148. The Bethell Process was also patented in England in 1838, and its cheapness and effectiveness have given it a considerable commercial success, both in Europe and the United States. It consists in the saturation of the wood with bituminous substances obtained by the distillation of coal tar.

Like the metallic salts, these substances produce coagulation of the albumen, and thus destroy the tendency to fermentation. Timber thus prepared is rendered very durable, and the process is comparatively inexpensive. Its use has, however, been given up, in some instances after extended trials, on the ground that the increase in durability was not sufficient to compensate for the expense.

Each cubic foot of timber, under a pressure of 150 pounds per square inch (10.5 kilogrammes per square centimetre), absorbs, in twelve hours, from eight to twelve pounds (1.55 to 0.23 kilogrammes to the cubic decimetre) of the creosote or dead oil.

The smaller amount is the allowance advised for railroad cross-ties. Hard woods absorb least. The strength of timber preserved by this method is unimpaired, and it requires no painting, although, with dry timber, a superficial coating of coal tar is sometimes added. This process has special advantages where the timber is exposed to alternations of dryness and moisture, and is therefore liable to wet rot. The dead oil fills the pores completely, coagulates all albumen, and absorbs all oxygen that may exist free in the wood, and, by its poisonous qualities, it acts as a protection against the attacks of insects. It does not, however, afford perfect protection against the ravages of the white ant of tropical countries. Even marine insects usually avoid creosoted timber, and wood so prepared is therefore used to a considerable extent in submarine work.

The antiseptic element of dead oil is supposed to be the carbolic acid, which is estimated by Prof. Letherby at from one and one half to six per cent. of the whole.

The cost of creosoting 1,000 cubic feet (37.9 cubic metres), board measure, of oak or spruce fir, has been given at from five to eight dollars.

149. The Seely, the Robbins, the Leuchs, and the Hayford Processes are American modifications of the Bethell process.

The SEELY PROCESS consists in subjecting the wood to a temperature between 212° and 250° Fahr. (100° and 121° Centi-

grade) in a bath of creosote oil, for a sufficient length of time to expel all moisture. When all water is thus expelled the pores contain only steam. The hot oil is then quickly replaced by a bath of cold dead oil. The steam in the pores of the wood is thus condensed, and a vacuum is formed, into which the oil is forced by atmospheric pressure and by capillary attraction.

From six to twelve pounds of creosote oil to the cubic foot (0.7 to 1.4 kilogrammes per cubic decimetre) of wood is expended in this process. The amount is dependent upon the use to which the wood is to be put. For piles or other timber exposed to the depredations of worms, twelve pounds is used. An impregnation of ten pounds to the cubic foot costs twenty-five cents. For work in wheel-pits and under foundations, at least ten pounds per cubic foot (1.118 kilogrammes per cubic decimetre) should be used. For piles the usual charge is thirty cents per cubic foot.

The ROBBINS PROCESS consists in treating wood with coal tar or oleaginous substances in the form of vapor.

The wood is placed in an air-tight iron chamber, connected with which is a still or retort, heated by a furnace. When heat is applied, the vapor of naphtha is generated at a temperature of 250° to 300° Fahr. (121° to 149° Centigrade), the creosote oil vapor at 360° to 400° (182° to 204° Centigrade), and the heavier tar oils at 500° to 600° Fahr. (260° to 316° Centigrade). The wood is thus exposed from six to twelve hours.

By this process it would seem impossible to charge the wood with more than a fraction of the amount of carbolic acid and of other component parts of coal tar expended in the Seely process. The latter process is decidedly an improvement on the process of Bethell.

The cost of creosoting 1,000 cubic feet, board measure, of oak or of spruce fir, has been given as from five to eight dollars.

THE LEUCHS PROCESS, as perfected by Hock, is applied to cross-ties in the following manner:

The ties are introduced into an iron cylinder or reservoir

heated on the outside by a steam jacket. The wood, already as dry as possible, is raised to the highest degree of desiccation by the introduction of steam into the jacket, and when no more vapor escapes from it, a solution of paraffin is forced into the cylinder through a tube, by compressed air. This cylinder has a refrigerating coil which discharges into a closed receiver. Then steam is let into the jacket again. The water boiling and the vapor of petroleum not being able to escape, the pressure inside the cylinder rises to 75 or 100 lbs. per square inch (5.25 or 7 kilogrammes per square centimetre), at which pressure the wood is completely impregnated with the liquid.

When this operation has been prolonged sufficiently, heating is stopped, and the operator waits until the pressure has fallen, and the excess of paraffin can be drawn off into the reservoir. The wood is again heated. When all remaining vapor of petroleum has been absorbed, air is blown into the cylinder to drive out gas, which might incommode workmen while removing the wood.

The paraffin remains distributed among the ligneous fibres, enveloping them with a thin coating, at the same time filling the pores and cellular spaces. The wood is thus well protected against moisture. Nails driven into wood so treated, do not rust as in wood impregnated with metallic salts, and the preserved wood retains its value as fuel.

THE HAYFORD PROCESS is one in which the wood is placed in a cylindrical boiler, into which steam is admitted and atmospheric air forced, until there is attained a pressure of 30 to 40 pounds per square inch (2.1 to 2.8 kilogrammes per square centimetre), and a temperature of 250° to 270° Fahr. (121° to 132° Centigrade), which pressure and temperature suffice to evaporate the sap of boards and two-inch (5.08 centimetre) plank in four or five hours—ten or twelve hours being required for heavy timber. After this, the vaporized sap and steam condensations are drawn out by air pumps. A vacuum is then produced which completely withdraws the vaporized sap from the very heart of the wood. The oil is admitted to the wood through perforated pipes arranged

around the interior of the cylinder, under pressure such as, with the partial vacuum within the cylinder, is equivalent to about 75 pounds to the square inch (5.25 kilogrammes per

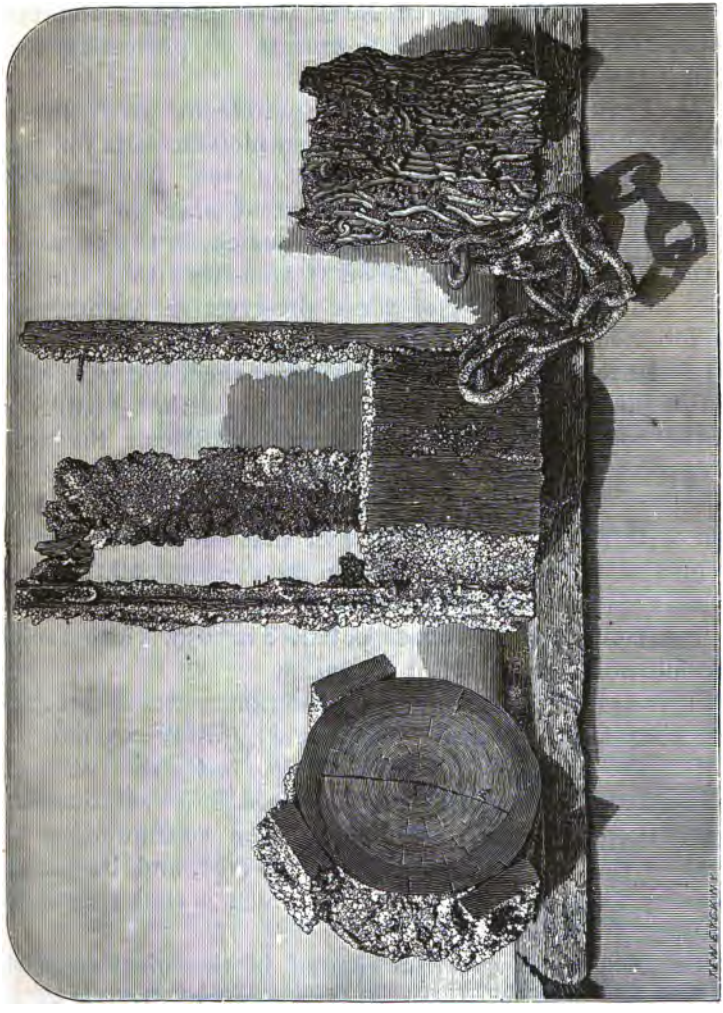

FIG. 52.—WOOD CREOSOTED AND UNCREOSOTED.

square centimetre). This is sufficient to cause the oil to penetrate the more porous woods. For those which are more dense, a further pressure of 60 to 150 pounds (4.2 to 10.5

kilogrammes per square centimetre) is required for a certain length of time.

The illustration on the preceding page exhibits the condition of timber thus creosoted, and uncreosoted, exposed in sea water at Wilmington, N. C. Creosoting is at present considered the most valuable process of protecting wood against the teredo.

M. Paulet considers that the petroleum products containing phenic acid are preferable to metallic salts for treating wood exposed to the action of sea water, because naphthaline, and especially phenic acid, have an antiseptic power, coagulate the albumen, and thus check the circulation of the sap, and also of the blood of parasites ; that the volatility and the solubility of these preservative agents would render their antiseptic action temporary only, if the more fixed and thicker oils which accompany them did not enclose and retain those substances, at the same time obstructing all the pores of the wood, and rendering difficult the access of dissolving liquids and destructive gases ; but that grave objections have been raised, based upon restricted production of these oils, and on the fact that the wood thus impregnated is inflammable, while on the contrary, all the metallic salts render wood uninflammable.

150. Boucherie's Process, patented in 1839, is an ingenious and inexpensive method of saturation.

This process attracted much attention, and was practiced with considerable success. The timber, freshly cut, and with its terminal foliage still remaining, was set either vertically or horizontally, with the foot immersed in a vat containing the antiseptic solution. The circulation continuing in the trunk of the tree, the sap becomes ejected, and its place is taken by the preservative solution, which is thus thoroughly distributed throughout the fibre.

Growing trees were also treated by the injection of the liquid into their trunks. Where logs, deprived of their foliage and branches, were to be saturated, they were placed on end, and a waterproof bag, or a tank, containing the solution used, was mounted above it, the liquid being thus forced down-

ward through the stick by hydrostatic pressure, driving the sap before it and out of the lower end.

The antiseptic proposed by Dr. Boucherie was crude *pyrolignite of iron.* His process of saturation was largely used with other preservatives also, and his invention of the saturating process seems to have been more generally appreciated than his introduction of a cheap antiseptic. Where it can be conveniently applied, it is exceedingly efficient.

Numerous and elaborate experiments were tried by Dr. Boucherie, in which the action of pyrolignite of iron was carefully noted. He found that one-fiftieth of the weight of the green wood was a sufficiently large proportion of the antiseptic to insure preservation. The hardness of the wood was stated to be doubled by the use of the pyrolignite.

151. Solutions of deliquescent salts were applied by Dr. Boucherie in the way described, and were found, in the case of chloride of lime and some others, to increase the flexibility of timber. He therefore proposed the use of such solutions, with the addition of one-fifth their quantity of pyrolignite of iron, when it was desired that the wood should retain its moisture, and its flexibility and elasticity. The same inventor proposed, as a cheap substitute for these solutions, the stagnant water of salt marshes. Such preparation, it was claimed also, prevented the warping and splitting of wood, which is a frequent consequence of rapid drying, and yet seasoning was said to be expedited by its use. In this case, the solutions were weak, and the wood could be afterward painted over without difficulty. The process was applied by the inventor to the saturation of timber with earthy chlorides, as a protection against fire. These salts, fusing upon the surface of the wood on the application of heat, rendered it quite incombustible.

Wood was dyed with both mineral and vegetable colors by Dr. Boucherie, and the application of the usual method of producing "fast" colors, by the introduction of dye and mordant successively, was thus made practicable. Wood was treated with odorous solutions to give it fragrance, and with resinous matters to make it water-proof.

The French Government, after receiving favorable reports from the Commission of Engineers appointed to examine into the merits of the process, finally conferred upon the inventor the great gold medal of honor. Subsequently a money award was made him, and he surrendered his patent, which thus became public property. This is still considered one of the best processes yet devised.

152. "Beerizing" consists in the saturation of the timber, by any convenient process, with a solution of borax. This is claimed to dissolve the albumen, and the solution may be allowed to remain, the borax having antiseptic properties, or it may be washed out, and the wood then dried is stated to become more thoroughly seasoned and durable than it can be made by the ordinary process of seasoning.

153. Folacci's Process of securing incombustibility and impermeability of woods consists in their impregnation with a composition consisting of:

Sulphate of zinc	25 parts.
Potassa	10 parts.
Alum	20 parts.
Oxide of manganese	10 parts.
Sulphuric acid at 60° B	10 parts.
Water	25 parts.
	100 parts.

These chemicals are mixed and heated without the sulphuric acid to a temperature of 45° Centigrade (113° Fahr.), and the acid is then added gradually until solution is completely effected.

It may be applied by Boucherie's or by any other convenient method.

154. Margery's Process of saturation with sulphate of copper has been found very effective in some instances.

It was applied by the Boucherie method to telegraph poles and to railroad cross-ties many years ago in France, with perfect success as a preservative against decay. When thus prepared telegraph posts last from fifteen to twenty years. They are subjected to the process in the forest di-

rectly after cutting, and while yet full of sap; the expense of thus treating them is usually from one to one and a half dollars per post. The wood is more rapidly and perfectly protected in proportion as it is porous and rich in sap. After undergoing the preservative process the timber is seasoned and becomes very light and portable. Nearly all the posts of the French, German, and Belgian telegraph service are now treated by this process.

The salt used is poisonous to vegetable and animal parasites which appear at the beginning of all organic decomposition. The quantity of the salts of copper should be increased when the wood is intended to be immersed in water or buried in a moist soil, as water dissolves this salt slowly.

There is in wood impregnated with the salts of copper a portion of the sulphate closely united with the ligneous tissue, and another portion in excess remaining free; this latter portion dissolves first, and, carried off by the exterior fluids, only retards the loss of the metallic salt combined with the wood; but this combination itself, although more stable, does not escape removal, which is accelerated or retarded according to the rapidity and ease with which the dissolving liquid is renewed. The quantity of metallic salt should be small in wood intended for constructions in the open air, in order to prevent mechanical injury due to crystallization. Major Sankey found this process equally efficient in India, more recently, as a protection against the attacks of the white ant and other insects. He used a solution of one pound of the salt in four gallons (1 kilogramme to 33⅓ litres) of water. The timber was steeped in the solution two or two and a half days for each inch (2.54 centimetres) in thickness.

A simple coating of *boiled linseed oil* thickened with powdered charcoal, has in some cases been found a very economical and efficient preservative of timber.

155. **Statistics** of railroad construction have given the following data:

Of unprotected oak cross-ties on European roads, 25 per cent. were renewed in 12 years, and 50 per cent. in 17 years. When impregnated with chloride of zinc, 3¼ per cent. were

renewed in 7 years, and 20 per cent. in 17 years; when protected by "dead-oil," 0.1 per cent. were replaced in 6 years.

Of pine cross-ties impregnated with chloride of zinc, 4½ per cent. were renewed in 7 years, and 31 per cent. in 21 years.

Of ties of beech, protected by creosote, 45 per cent. were replaced in 22 years.

On the railroad from Hanover and Cologne to Minden, of pine ties injected with zinc, 21 per cent. were renewed after 21 years; of beech ties injected with creosote, 46 per cent. after 21 years; oak not injected, 49 per cent. after 17 years; oak ties injected with chloride of zinc, 20.7 per cent. after 17 years. The ties not renewed appeared perfectly sound.

In all these cases the ties were laid in favorable situations.

It was reported to the German Railway Union, in 1881, that, on the railways of Europe, chloride of zinc was most generally used for preserving timber, and creosoting next, while the use of sulphate of copper was declining. Preservation with chloride of zinc cost less than one half as much as creosoting. Seasoning was considered desirable before creosoting, but not when using the salts of zinc.

156. **The importance of the preservation of timber** is daily increasing, not only as a matter of ordinary economical policy, but because the rapid destruction of forests is continually rendering timber more scarce and more costly. It will become a matter of such vital necessity to preserve our forest trees, that legislation will soon inevitably aid in increasing the market value of timber by forbidding its wholesale destruction.

The substitution of iron for wood, in construction, is proceeding so rapidly, that it will afford some relief; but the preservation of timber will nevertheless remain a matter of exceptional importance.

H. W. Lewis, writing in 1866, says: "Allowing only 2,000 sleepers to a mile (1.6 kilometres), at a cost of fifty cents each; and admitting the average life of American sleepers

(cross-ties) to be only seven years, and that it costs ten cents to treat each tie in some way so as to make it last fourteen years, then the saving at the end of seven years is $600 per mile."

There are in the United States* over 100,000 miles (160,000 kilometres) of railroad; and hence, if the above conditions could be realized on all of them, the annual saving would be over $60,000,000.

Our railroads are still rapidly extending, and the other uses to which timber is put, which allow of the application of preservative processes, are many and important. The value to the country, and to the world, of effective and cheap processes of preservation, cannot be estimated.

157. Comparison of Processes.—The following tabular statement of experimental results obtained by various processes was given in a report to the Board of Public Works of the District of Columbia, as derived from an examination of those methods, by Drs. B. F. Craig and W. C. Tilden, of the U. S. Army, in the laboratory of the Surgeon General's Office, at Washington:

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*1882

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TABLE XXVII.

MINERAL AND METALLIC PROCESSES.

NAME AND NUMBER.	BRIEF OF CLAIM.
Burnettized Spruce. Two specimens. Nos. 2 and 9. (No. 2 is a piece of railroad tie, said to have been buried sixteen years.)	"The Burnettizing process consists in placing the wood in large wrought-iron cylinders; then extracting the air and sap contained in the pores of the wood by a vacuum. The solution of chloride of zinc is then allowed to run in, and a pressure of from 150 to 160 lbs. per square inch applied to force the zinc into the pores." Perfect coagulation of albumen and entire indestructibility by wet or dry rot are claimed.
A. B. Tripler's Arsenic Process. One specimen. No. 14.	Saturation of blocks composing a wooden pavement with chloride of arsenic, or arsenic and chloride of sodium, and coating them on their upper surface with a resinous or tarry waterproof composition. Also, the interposition of an antiseptic compound between the blocks and the earth, by either soaking the foundation planks or mixing the antiseptic with the sand.
The Samuel's Process. Nos. 8 and 5 (?).	"Injecting into the pores of the wood, first, a solution of sulphate of iron, and afterwards a solution of common burnt lime, to render the wood in a high degree impervious to the influence of wet and dry rot, and the attacks of worms and other insects."
Thilmany's Process. One specimen. No. 15.	Saturation with sulphate of copper, followed by muriate of barytes, to form insoluble sulphate of barytes in the wood.
Process of Wirt and Hurdle. Specimens 18(a) and 18(b).	Charring the wood and covering the whole block with asphaltum.
Tait's Process. One specimen said to have been sent, marked No. 5. Analysis, however, places this block with No. 8, as a sample of the Samuel's process.	"Charging or saturating the pores of the wood with a concentrated solution of bi-sulphite of lime or baryta. the same being rendered soluble by excess of sulphuric acid gas, under pressure or by refrigeration, and being made insoluble as a neutral sulphate when the pressure or excess of gas is removed."
Thomas Taylor's Process. Two specimens. Nos. 19 & 20.	Uses a solution of sulphide of calcium in pyroligneous acid for the impregnation of the wood: or, uses sulphide of calcium first, and follows it with pyroligneous acid. Claims a deposit of pure sulphur through whole block.
Thompson & Co.'s Process. (Arsenic.) No. 17.	No description or explanation of process furnished. Claims "indestructibility" and "non-inflammability."

TABLE XXVII.—(*Continued.*)

MINERAL AND METALLIC PROCESSES.

REMARKS.
Fibre of blocks weak and brittle; color grayish. Absorptive power greater than that of natural wood. All of the zinc easily removed by acidulated water. Evidences of the partial decomposition of the zinc chloride observed. Uneven character of impregnation shown both by microscopic examination and by unequal percentage of mineral matters removed by acidulated water from the centre and near surface. (See Columns 3 and 4 of Experimental Results.)
Size of specimen very small, yet the impregnation uneven. (See columns 3 and 4.) Quantities of soluble salts very large. No arsenic found, though its use is claimed. The resinous covering designed to protect the top of each block is worthless for the purpose, for obvious reasons, chiefly its brittleness. Absorptive power high.
Absorptive power too high for representation on the chart. Wood brittle and readily splintered. Impregnation very unequal. The water used for experiment No. 1 (absorptive), was filled with threads of fungi after standing forty-eight hours, showing that it is doubtful if even dry rot can be prevented by this process.
Saturation very uneven. Absorptive power high. Block contains soluble salts of copper removable by washing.
Process inapplicable to unseasoned timber. The asphalt covering melts and flows at 60° to 70° F. When cold and brittle, the wear of the pavement will remove it, leaving each block as a porous cup for the reception of water which cannot drain through it. Process not considered worth particular investigation.
It is doubtful if any specimen was received. No. 5 resembles the "ironized" blocks. If claimed as a sample of the Tait process, the same memoranda are made upon it as upon No. 8.
The claims of this process are not substantiated. No sulphur uncombined found in any part of the blocks submitted. About nine-tenths the whole bulk of each block possessed every property of seasoned white pine untreated by any method whatever. Between three and four per cent. sulphate of lime found in superficial portions.
Arsenic process. Absorption power high. Specimen is cottonwood. Saturation extremely uneven. Solubility of saline ingredients complete.

TABLE XXVII.—(*Continued.*)

CREOSOTE, OIL, AND RESIN PROCESSES.

NAME AND NUMBER.	BRIEF OF CLAIM.	REMARKS.
Waterbury's Process. One Specimen. No. 1.	Treats wood in closed cylinder with steam to vaporize sap; then introduces a solution of *common salt*, followed by *dead oil*, *creosote oil* or equivalent. Claims complete impregnation by both substances.	Absorption figures high. Saturation by solution of common salt is only partial. Columns 3 and 4 show a very uneven penetration by "*dead oil.*" Water dissolves out all the salt used. Columns 5 and 6 show the uneven distribution of mineral matters.
Thomas's Process. Two Specimens. Nos. 3 and 13.	Two small blocks, 2 x 6 x 1 and 4 x 5 x 3 in., were sent without explanation or name; the substance used for impregnation is "resin oil."	Absorption power low. Physical condition of specimens very bad. Saturating material easily soluble in alkaline fluids. The strength of wood in these samples stands at a minimum, especially its transverse and crushing strength.
Seely's Process. Five Specimens. **Pelton's Apparatus for applying Seely Process.** Nos. 4, 6, 7, 12, 22.	Immersion of wood in a bath of *creosote oil* or other suitable material, heated to about 250° F., until it is evident that air and moisture are eliminated; then substituting for the hot bath, one at as low a temperature as allows perfect fluidity, the liquor being also *dead oil.* Claims that the pores of the wood are in a vacuous condition as it cools, and that the impregnating material readily fills them by capillary action and atmospheric pressure.	Average absorption power very low. Saturation thorough and very uniform. (See Columns 3, 4, 9, and 10.) Solid hydrocarbons present within the cells. Condition of fibre uninjured.
Robbins' Process. Two Specimens. Nos. 10 and 20.	Claims to impregnate wood with *light and heavy oils of tar*, by exposure in a chamber connected with a *retort* or *still* in which the oils are *vaporized;* states that naphtha and other solid hydrocarbon bodies are distilled over into the wood and condensed in its pores; also that all moisture is driven out and the albumen coagulated.	Absorption power very high. Percentage of liquid hydrocarbons very low in all portions of block except the outer. No solid hydrocarbons observed, even on surface. Condition of wood shows injury from heat. Specimens are evidently suited for exposure to *dry air* only, under which circumstances the protection is sufficient.
Detwiler and Van Gilder Process. No. 11.	Impregnation of wood by *resin* dissolved in *naphtha*, under pressure, and at high temperature.	Saturation uneven. (Columns 3 and 4, also 9 and 10.) Absorption power quite high.
U. S. Antiseptic Wood Co.'s Process. Constant and Smith Patents. No. 15.	*Dries* or *seasons* wood by *hot air;* preserves it (when desired), by generating "*smoky vapors*" in a retort, the same being allowed to penetrate the wood and to condense within its pores.	The same remarks made under Nos. 10 and 20 (Robbins' process), apply to this specimen, with the difference that the experimental results show the Robbins process to be very much superior to this, which presents identical claims.

TABLE XXVII.—(*Continued.*)

EXPERIMENTAL RESULTS.

Number and size of each block as received.	1 Absorptive power (per cent. of distilled water absorbed in 48 hours).	2 Per ct. of solution and mechanical removal in the preceding experiment.	3 Per cent. of matters dissolved by the proper solvents from the centre of each block.	4 Per cent. dissolved from the superficial portions of each block.	5 Ash, per cent. at centre.	6 Ash, per cent. near the surface.	7 Apparent specific gravity at centre of each block.	8 Apparent specific gravity of superficial portions of each block.	9 Weight of one cubic foot of density of column 7.	10 Weight of one cubic foot of density expressed in column 8.	11 Reaction of the Wood.
	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.			lbs.	lbs.	
1.—8x3x5 in.	24.29	1.00	4.55	33.8	1.72	13.5	0.412	0.568	25.1	35.5	Acid.
2.—8x8x4¼ in.	47.90	0.21	2.34	7.7	1.86	6.2	0.443	0.472	27.6	29.5	Acid.
3.—2x6x1 in.	5.08	0.43	7.7	5.08	0.33	0.4	1.116	1.007	69.7	62.9	Acid.
4.—4x6x2 in.	7.25	0.39	35.4	40.00	2.1	.....	0 707	0.700	44.1	43.7	Faintly Acid.
5.—4x4¼x2 in.	46.64	1.01	2.64	9.55	1.63	7.2	0.619	0.6706	38.6	41.9	Faintly Acid.
6.—10x6x4 in.	3.32	0.16	centre& surface 17.	.. ...	0.35	.....	0.5608	0.650	35.0	40.6	Faintly Acid.
7.—9x4x1 in.	8.46	0.33	centre& surface 22.8	.....	0.45	.....	0.845	.....	52.8	... ..	Faintly Acid.
8.—6x6x3 in.	97.58	0.46	1.55	3·3	1.45	5.4	0.484	0.498	40.2	41.1	Faintly Acid.
9.—7x6¼x5 in.	31.36	0.26	1.16	3.45	1.45	1.60	0.4609	0.439	28.8	27.4	Acid.
10.—12x6x3 in.	22.80	1.00	1.96	12.25	0.52	.....	0.4202	0.445	26.2	27.8	Faintly Acid.
11.—12x6x4 in.	16.15	0.5	14.83	23.7	0.38	.....	0.7005	0.833	43.7	52.0	Faintly Acid.
12.—12x7x4 in.	13.54	0.10	16.2	17.6	0.29	.....	0.601	6.633	37.5	39.5	Faintly Acid.
13.—4x5x3 in.	2.88	0.13	35.07	41.4	0.36	.....	1.095	1.064	68.4	66.5	Acid.
14.—6x3x2 in.	21.27	5.44	31.3	73.5	21.9	24.8	0.455	.....	28.4	.....	Acid.
15.—8x6x3 in.	23.19	0.29	10.8	13.4	0.52	.....	0.6004	0.617	37.5	38.5	Faintly Acid.
16.—10x6x3 in.	29.11	0.59	1.91	7.5	1.8	3.8	0.449	0.554	28.0	34.6	Acid.
17.—10x6x3 in.	31.98	9.54	9.17	67.0	6.74	38.8	0.449	0.541	28.0	33.8	Neutral
18.—5x4x3 in.	28.93	0.16	.. ....	.....	.....	.....	0.493	.....	30.8	.....	
19.—5x4x3 in.	62.74	0.64	.....	.....	.....	.....	.. ...	.....	.....	.....	Acid.
20.—10x6x3 in.	78.10	0.21	.....	.....	.....	.....	0.429	.....	26.8	.....	
21.—	.....	.....	1.57	4.7	1.63	.....	0.519	.....	.....	.....	
22.-Small piece from a pavement in N. Y., laid three years.	.....	.....	35.	.....	.....	.....	0.407	.....	25.4 (very dry)	.....	

158. Special Adaptations of the Various Woods are exhibited in the following table. (See also § 135, *et seq.*)

TABLE XXVIII.

CARPENTRY.

Cherry,	Pine, Yellow,	Walnut, Black.
Chestnut,	" White,	
Maple,	Spruce, Fir, or Deal,	

SHIP BUILDING.

Cedar,	Locust,	Pine, White,
Cypress,	Mahogany,	" Yellow,
Elm,	Oak, English,	Teak.
Hackmatack,	" Live,	
	" White,	

MACHINERY AND MILL-WORK.

BEARINGS.

Beech,	Holly,	Maple.
Box,	Lignum Vitæ,	
Elm,	Oak,	

FRAMING.

Ash,	Elm,	Pine, Yellow,
Beech,	Hickory,	Spruce or Deal.
Birch,	Oak,	

PATTERNS.

Cedar,	Ebony,	Pine, White.
Cherry,	Mahogany,	Spruce or Deal.

ROLLS.

Box,	Lignum Vitæ,	Oak.
Hickory,	Locust,	

SHEAVES.

Box,	Lignum Vitæ,	Mahogany
Ebony,		

TURNING.

Alder,	Ebony,	Plum,
Apple,	Elm,	Poplar,
Beech,	Holly,	Sycamore,
Birch,	Horse Chestnut,	Walnut,
Box,	Locust,	Willow.
Cherry,	Mahogany,	
Dogwood,	Pear,	

and, generally, any close-grained wood, having a good degree of lateral cohesion.

TEETH OF MORTISE-GEARING.

Apple, Sour,	Elm,	Locust,
Beech,	Hickory,	Oak.
Crab Apple,	Hornbeam,	

SPECIAL PROPERTIES.

STIFFNESS AND ELASTICITY.

Ash,	Hickory,	Spruce or Deal,
Cedar,	Lancewood,	Walnut, Black,
Chestnut,	Locust,	Yew.
Hazel,	Mahogany,	

TOUGHNESS AND STRENGTH.

Beech,	Hornbeam,	Oak, White.
Elm,	Hickory,	" Live.
Lignum Vitæ,	Lancewood,	

FINE UNIFORM GRAIN.

Beech,	Holly,	Pine, White.
Box,	Lime,	
Cherry,	Pear,	

DURABILITY (DRY).

Cedar,	Locust,	Pine, Yellow,
Chestnut,	Oak,	Teak.
Cypress,	Poplar,	

DURABILITY (WET).

Alder,	Larch,	Pine, Pitch,
Elm,	Locust,	" Yellow,
Greenheart,	Oak.	Teak.

ORNAMENTAL WOODS.

Amboyna,	Ebony,	Partridgewood,
Beef Wood,	Greenheart,	Purplewood,
Box,	Ironwood,	Rosewood,
Brazilwood,	Lignum Vitæ,	Sandalwood,
Camwood,	Locust,	Satinwood,
Cedar,	Mahogany,	Tulipwood,
Cocoawood,	Maple,	Walnut, Black.
Coffee,	Olive,	

FRAGRANT WOODS.

Cedar,	Rosewood,	Satinwood,
Camphor,	Sandalwood,	Sassafras.

DYE WOODS.

Red—Brazil,	Red Sander,	Green—Green Ebony.
Camwood,	Sapan.	Yellow—Fustic,
Logwood,		Zamite.

CHAPTER IV.

FUELS.

159. The Fuels used in Metallurgy and Engineering are anthracite and bituminous coals, coke, wood, charcoal, peat, and combustible gases obtained by the distillation of the solid kinds of fuel.

The oils—animal, vegetable, and mineral—and the solid hydrocarbons, of which bitumen is a type, are occasionally used also. All consist of either pure carbon or of combinations of carbon, hydrogen, and non-combustible substances.

Wherever metals are to be worked, and the fuel brought into direct contact with them, it is usually advisable to select fuel which is most free from sulphur and phosphorus, these elements being usually most injurious to the product. In making a selection the engineer is aided greatly by a knowledge of the origin and general characteristics of those fuels from which he may be called upon to select the one best adapted to any given case.

160. The Heating Power of any fuel is determined by calculating its *total heat of combustion.* This quantity is the sum of the amounts of heat generated by the combustion of the unoxidized carbon and hydrogen contained in the fuel, less the heat required in the evaporation and volatilization of constituents which become gaseous at the temperature resulting from the combustion of the first named elements.

A *thermal unit* is the quantity of heat necessary to raise a unit weight of water, at temperature of maximum density, one degree of temperature. The British thermal unit is the quantity of heat required to raise a pound of water from the temperature 39°.1 to 40°.1 Fahr. The metric unit or calorie is the quantity of heat required to raise one kilogramme of water (2.2046215 pounds) from 3°.94 to 4°.94 Centigrade.

One metric or centigrade unit is equal to 3.96832 British units, and a British unit is equal to 0.251996 metric unit.

An approximate estimate of the number of thermal units developed by the combustion of a pound or kilogramme of any dry fuel, of which the chemical composition is known, may be obtained by the use of the following formula:

$$\left.\begin{aligned} h &= 14{,}500\ C + 62{,}000\left(H - \frac{O}{8}\right), \quad . \quad . \\ h' &= 8{,}080\ C + 34{,}462\left(H - \frac{O}{8}\right), \quad . \quad . \end{aligned}\right\} (1),$$

where h is the number of British thermal units representing the total heat of combustion of one pound of the fuel; h' is the number of metric units per kilogramme of fuel; C represents the percentage of carbon; H that of hydrogen; and O that of oxygen.

Thus an anthracite coal has been found to have the following composition:

COMPOSITION OF ANTHRACITE COAL.

	Per cent.
Carbon	81.34
Hydrogen, *uncombined*	3.45
Hydrogen, *in combination*	0.74
Oxygen and Nitrogen	5.89
Sulphur	0.64
Water	2.00
Ash	5.94
Total	100.00

One pound or kilogramme of coal, of which the above is an analysis, can evaporate theoretically 14.4 pounds or kilogrammes of water from and at 100° Centigrade, or 212° Fahr.

The value of h or of h' ranges between 5,500 British or 1,386 metric units for dry wood, and 16,000 or 4,032 for the best known coals. The equation given is deduced from the experiments of MM. Favre and Silbermann, who determined the total heat of combustion of one pound of pure carbon to be 14,500 British or 3,654 metric thermal units, and

of one pound of hydrogen to be 62,000 British units, or 15,624 calories. The combustion of one kilogramme of each would develop 31,967 British or 8,080 metric units, and 136,686 British or 34,462 metric units respectively.

The combustion of the several kinds of carbon produces the development per unit of weight of:

BRITISH UNITS.	METRIC UNITS.	MATERIAL.
13,986	7,770	Diamond.
13,968	7,760	Iron Graphite.
1,4040	7,800	Natural Graphite.
1,4490	8,050	Gas Carbon.
14,500	8,080	Wood Charcoal.

Where the chemical composition of the fuel is unknown and cannot be readily ascertained, its heating effect may be determined experimentally by burning a known weight and passing the products of combustion through a calorimeter of such area of heating surface as to reduce their temperature very nearly to that of the atmosphere before discharging them.

The table given hereafter exhibits the total heating effect of various fuels as estimated from analyses of good specimens.

Where the heat produced is not so thoroughly utilized as to cause the condensation of vapors which may pass off with the permanent gases resulting from combustion, there is necessarily a greater loss of the heat of combustion of hydrogen than of that of carbon, and the relative heating efficiency of carbon is considerably increased by the facts that it must be raised to red heat as a solid before combustion can occur, and that the specific heat of carbonic acid (0.216) is only about one half that of aqueous vapor (0.475).

161. The Temperature of the Fire depends, not solely on the amount of heat generated by combustion, but also on the quantity and nature of the resulting products of combustion.

The total heat generated by the combustion of fuel is all communicated to the products of combustion, which are usu-

ally gaseous, giving them a temperature which is determined, partly by the calorific power of the fuel, and partly by their nature. Thus, carbon requires for its combustion to carbonic acid, 2.67 times its weight of oxygen, producing 3.67 times its weight of carbonic acid.

The heat generated by combustion of carbon is capable of raising 8,080 times its weight of water from 4° to 5° C., and would raise the temperature of water equal in weight to the carbonic acid produced, about 2,202° C.*—*i. e.*: 8,080 × 1° = 2,201°.63 × 3.67.

But the specific heat, or capacity for heat, of water is greater than that of carbonic acid; the increase of temperature in the carbonic acid produced is correspondingly greater than the rise in temperature that would be produced in a quantity of water equal to 3.67 times the weight of carbon burnt. The quantities of heat necessary to produce equal increase of temperature in equal weights of carbonic acid and of water being in the proportion of 0.2164: 1.0000, the amount of heat needed to raise the temperature of 3.67 parts water and 3.67 parts carbonic acid one degree, are as

$$\frac{3.67}{3.67 \times 0.2164} = \frac{3.67}{0.794}.$$

Hence the rise in temperature of the 3.67 parts of carbonic acid, to which the heat of combustion of 1 part carbon is transferred, may be calculated by dividing the given number of heat units by the amount of heat required to raise the temperature of the 3.67 parts carbonic acid one degree, or

$$\frac{8080}{0.794} = 10{,}174° \text{ C.} = 18{,}345° \text{ F.}$$

The heat of combustion of hydrogen is sufficient to raise the temperature of 34,462 times its weight of water, 4° to 5° Cent., but it requires for its combustion 8 times its weight of oxygen, and produces 9 times its weight of vapor. The products of combustion weigh nearly 2½ times as much as those of the

* Watts' Dictionary of Chemistry.

combustion of an equal weight of carbon. Some of the heat produced by the combustion of hydrogen becomes latent and does not increase the temperature of the gases.

The latent heat of water, or that needed to convert 1 part of water at 100° C. into steam, is 537 times as much as is needed to raise the temperature of an equal weight of water from 4° to 5° C., and 966.1 times the quantity which will raise the temperature of one part from 39°.1 to 40°.1 Fahrenheit. The quantity of heat latent in the 9 parts vapor produced by the combustion of hydrogen will therefore be 4,833 metric heat units; this must be taken from the total amount of heat generated in calculating the quantity of heat producing rise in temperature.

	Parts by weight of water vapor.	Metric Heat units.		British Heat units.
Total heat of combustion of 1 part hydrogen		34,462		62,000.0
Latent heat of water in heat units	9 × 537 =	4,833..9	× 966.1 =	8,694.9
Available heat		29,629	=	53,305.1

The specific heat of water vapor is 0.475, the heat raising the temperature of 9 parts water and 9 parts water vapor have the proportion,

$$\frac{9 \times 1}{9 \times 0.475} = \frac{9}{4.275},$$

and the rise in temperature will be

$$\frac{29629}{4.275} = 6930°.7 \text{ C.} = 12{,}475°.3 \text{ F.}$$

Thus the heating and the calorific power are not necessarily the same. The heating effect depends only partly upon the calorific power of the fuel burnt.

RECAPITULATION.

	WEIGHT.	WEIGHT OF OXYGEN.	RATIO.	WEIGHT OF PRODUCTS.	RATIO.	HEAT UNITS.	RATIO.	THERMAL EFFECT.	RATIO.
Carbon....	1	2.67	1	3.67	1	8080	1.000	10176°	1.000
Hydrogen.	1	8	3	9.00	2.4	34,462	4.265	6930.7°	0.681

In these examples combustion takes place in oxygen, and with no more than is theoretically needed. In all actual cases of combustion, atmospheric air supplies the oxygen supporting the combustion. Nitrogen, of which it contains 77 per cent., dilutes the products of combustion and reduces the temperature. In the case of combustion of carbon in air, the nitrogen in air containing 2.67 parts of oxygen amounts to 8.94 by weight.

The specific heat of nitrogen is 0.244, and the quantity of heat needed to raise the temperature of the nitrogen from 4° to 5° C. is:

$$8.94 \times 0.244 = 2.181 \text{ units.}$$

Adding to this the heat needed to raise the temperature of the carbonic acid produced, the amount of heat needed to raise the temperature of all the products of combustion in air from 4° to 5° C. will be:

$$2.181 + 0.794 = 2.975 \text{ units.}$$

And the elevation of temperature will be

$$\frac{8080}{2.975} = 2715° \text{ C.} = 4887° \text{ F.}$$

Burning hydrogen in air, the nitrogen in air containing 8 parts of oxygen, is, by weight, 26.78 parts, and the amount of heat needed to raise its temperature from 4° to 5° C. is:

$$26.78 \times 0.244 = 6.534 \text{ units,}$$

and the consequent rise in temperature will be

$$\frac{29629}{4.275 \times 6.534} = 2741° \text{ C.} = 4934° \text{ F.}$$

The difference between the temperatures attainable by the combustion of carbon and hydrogen in oxygen and in air is much the greatest with carbon, as the quantity of heat produced by its combustion is much less than that generated by burning hydrogen, thus:

RECAPITULATION.

	CALORIFIC POWER.	RATIO.	TEMPERATURE PRODUCED.				DIFFERENCE.	RATIO.
			In oxygen.	Ratio.	In air.	Ratio.		
Carbon.....	8.080	1.000	10,174°	1.000	2,715°	1.002	74,590	1.000
Hydrogen....	34.460	4.265	6,930°	0.681	2,741°	1.009	41,890	0.561

Thus in all cases where high temperatures are demanded, it is of advantage to increase the amount of oxygen in the air supporting combustion, and to restrict the influx of nitrogen and of superfluous air. Thus also the reason of the attainment of high temperatures by combustion in pure oxygen with the oxy-hydrogen blow-pipe is readily seen.

The quantity of air supplied is usually much greater than that simply required to furnish the oxygen to consume the combustible. In practice it often amounts to twice as much, and is rarely less than one and a quarter times the quantity theoretically needed, and there consequently follows a proportionate reduction of the temperature attainable. When carbon is burnt with twice as much air as is theoretically needed, the products of combustion have 24.22 times the weight of the carbon, and with hydrogen 80.56 times the weight of the hydrogen.

AIR REQUIRED TO SUPPLY A DOUBLE AMOUNT OF OXYGEN.

	PARTS BY WEIGHT OF AIR.	VOLUME OF AIR AT 60° F. PER LB. OF FUEL, CUBIC FEET.	PARTS BY WEIGHT OF GASEOUS PRODUCTS.
Carbon... .....1..	23.22	303.39	25.22
Hydrogen .....1..	79.56	908.62	80.56

The specific heat of air is 0.2377, and the quantities of heat needed to raise the temperature of the air demanded from 4° to 5°, and the temperature resulting from combustion are:

Combustion of carbon:

$$2.7597 = 11.61 \times 0.2377,$$

$$\text{and } \frac{8080}{2.797 + 2.9755} = 1{,}408° \text{ C.}$$

Combustion of hydrogen:

$$34.78 \times 0.2377 = 8.2672,$$

$$\text{and } \frac{29{,}629}{8.2672 + 10.8093} = 1{,}553^\circ \text{ C.}$$

It is evidently always desirable to secure perfect combustion, and with the least possible air supply. With the forced draught produced by a fan or blast-pipe, fuel may be burnt with less air than with a chimney, and draught can be utilized with greater economy of heat. This economy is greater with fuel containing but little volatilizable matter.

The general formulas, as given by Watts, for ascertaining the thermal effect of any fuel of a known composition are as follows:

For combustion in oxygen:

$$T = \frac{cC + c'H - lW}{s.3.67C + 9H + s'W}; \quad \ldots\ldots\ldots \quad (2)$$

For combustion in air:

$$T = \frac{cC + c'H - lW}{s.3.67C + 9H + s'W + s''N + s'''A}. \quad \ldots \quad (3)$$

Here T = increase of temperature produced by combustion;

C and H = quantities of carbon and hydrogen available in 1 part by weight of the fuel;

W = total quantity of water yielded by 1 part by weight of the fuel;

l = latent heat of water;

s, s', s'', s''' = specific heat of carbonic acid, water-vapor, nitrogen, and air;

c and c' = calorific power of carbon and hydrogen;

N = quantity of nitrogen in air necessary for converting combustible constituents of 1 part by weight of fuel into carbonic acid and water;

A = extra quantity of air supplied for combustion.

These formulas assume perfect combustion of the fuel into carbonic acid and water ; and express the highest possible results when burnt under the most favorable conditions.

In all ordinary cases, the effect actually obtained is much less than is indicated by this calculation, and may amount to but a small fraction of the calculated calorific effect.

162. The Mean Value of any Fuel may be estimated at about two-thirds those given in hereafter for good qualities.

As indicated in Equation (1), where oxygen exists in a compound, it will be found that only the excess of hydrogen over that required to unite with oxygen, will be found to yield heat by combustion.

It is evidently essential to the fullest utilization of the heating power of any substance, that the combustion shall be complete.

Carbon burned with an insufficient supply of oxygen, passes off in carbonic oxide, having taken up but one-half the proper proportion of oxygen, and yields but about two-thirds as great a quantity of heat as is due to complete combustion resulting in the formation of carbonic acid.

With ample air supply, at a proper temperature, carbonic acid combines with a further quantity of carbon equal to that which it already contains. This combination resembles in its effects the vaporization of ice by superheated steam. Instead of producing heat, there is a loss of heat, which may be considerable.

Thus, for example, as given by Watts:

	HEAT UNITS. CENT.	FAHR.
The heat generated by the combustion of one part of carbon to carbonic acid is.....	8,080	14,500
While the heat generated by the combustion of carbonic oxide to carbonic acid is.....	4,946	8,800
Loss of heat by production of carbonic oxide....	3,134	5,700.

This action takes place when fuel is burnt on a "heavy fire," and when it is burnt rapidly with imperfectly distributed air supply.

Hydrocarbons, under similar conditions, burn with the smoky flame which indicates the loss by unconsumed carbon. The production of soot and smoke in the burning fuel con-

taining the volatile hydrocarbons increases with increase in proportion of volatile matter, and in proportion to the quantity of carbon in the vapor. In soft bituminous coals the proportion of carbon in the gas is two or three times as great as in gases from wood.

This evolution of soot and smoke produces loss of heat, and hence a sufficient supply of air for perfect combustion must be provided by special means.

This air is often brought in through the furnace door or at the bridge wall, back of the fire, and is usually heated before it mingles with the products of combustion.

Watts illustrates the possible waste of heat resulting from the presence of volatilizable combustible substance in fuel by comparing the calorific power of Newcastle bituminous coal with that of its fixed carbon. Newcastle coal contains 60 per cent. of fixed carbon, and if only this portion of it is effective in generating heat, its calorific power may be taken as 0.60 that of carbon.

But the coal contains, then, 82.12 per cent. total carbon and 4.60 per cent. available hydrogen; its calorific power is, therefore,

$$0.8212 + (.046 \times 4.265) = 1.017,$$

and if the volatile matter were not burnt, the loss of heat would amount to 40 per cent., and if only the volatile carbon were left unburnt, the loss would be nearly 25 per cent.

The following table shows how great may be this waste of heat:

TABLE XXIX.

CARBON AND HYDROGEN IN FUELS.

	TOTAL CARBON.	AMOUNT OF CARBON VOLATILIZED.	AMOUNT OF HYDROGEN AVAILABLE.
Average wood	40.36	18.53	0.83
Peat	60.00	19 00	1.00
Bit. Coal, soft	77.90	22.56	4.13
Bit. Coal, medium	79.68	23.01	3.68
Bit. Coal, hard	78.53	28.34	4.40
Bit. Coal, "	82.12	25.22	4.60
Semi-anthracite	83.78	15.09.	4.27

Non-combustible substances in the fuel, and especially moisture, check combustion and produce a loss of heat.

Sulphur adds practically nothing to the calorific power of any fuel in which it may exist, and it is usually exceedingly injurious in metallurgical work.

The ash which is left after the combustion of those constituents of fuel capable of combining with oxygen, retards combustion by preventing the access of air to the combustible, and frequently where fusible by forming "clinkers" upon the grate bars, and thus choking the draught.

163. In metallurgical operations in which the fuel comes in contact with the materials which it is intended by its heat of combustion to reduce, it is not always essential, or possible, or even advisable, to secure the conditions of perfect combustion.

Carbonic oxide is a most valuable reducing agent, and it is, therefore, frequently necessary to provide for imperfect combustion, or for subsequent decomposition of the carbonic acid formed, in order to carry on reduction successfully.

The ash of the fuel is often valuable as a flux also, and it is, therefore, sometimes advantageous to use a fuel which would, on account of the amount of its ash, be rejected, were the object simply to obtain heat.

In the practice of metallurgy, the chemical composition of the fuel is often a matter of more consequence than its heating efficiency; and it should be determined with all the accuracy that circumstances will permit.

Where an analysis cannot be obtained, an assay of the ores proposed to be worked may be made, using in the assay samples of the proposed fuels, and the character of the fuel may be judged with some accuracy by the result of this assay. The effect, for good or evil, of the more commonly recurring impurities will be stated in detail in a succeeding article.

164. The minimum Quantity of Air required for the perfect combustion of any kind of fuel may be readily calculated from its known chemical constitution.

Calling the weight of air W, and denoting the weights of carbon, hydrogen, and oxygen, C, H, and O,

$$W = 12C + 36\left(H - \frac{O}{8}\right) \quad . \quad . \quad . \quad . \quad (4).$$

The value of W ranges from 6, for dry wood, to 12, for anthracite and good bituminous coal. Charcoal and the softer bituminous coals require about 11 parts by weight of air per 1 part of fuel.

These values can only be approximated, in practice, with extremely slow and carefully managed combustion. A perfect intermixture of the combustible with the supporter of combustion can only be secured by the admission of some excess of air to the furnace. Probably about double the estimated amount of air is usually provided, although, in some cases, where a forced draught produces exceptionally complete intermixture of the gases, the quantity may be brought as low as 18 pounds of air per pound of coal.

In one instance, in which a furnace burning wet fuel was tested by the author, to determine its economic efficiency, the quantity of air supplied was very little in excess of that dictated by theory. This was, however, an exceptional case. As the excess of air must be heated to the temperature of the chimney, and then thrown away, it causes a notable waste of heat.

The weight of a cubic foot of air at mean atmospheric temperature being 0.076391 pound, the *volume* of air required for perfect combustion, in any case, may be determined by the equation:

$$V = 157C + 471\left(H - \frac{O}{8}\right) \quad . \quad . \quad . \quad (5).$$

Eighteen and twenty-four pounds of air, required, as stated above for combustion, in the case mentioned, of one pound of coal, would measure, respectively, 236 and 314 cubic feet.

The weight of a cubic metre of air is 1.224 kilogrammes. The volume, in metric measures, required in any case is therefore:

$$V' = 9.8C + 29\left(H - \frac{O}{8}\right) . \quad . \quad . \quad . \quad . \quad (6).$$

When eighteen and twenty-four times the weight of fuel

are required respectively, the volumes in the case taken would be 15 and 19 cubic metres.

165. The Temperature of the Products of Combustion may be calculated, as has been shown, with approximation to accuracy, from the known weight of the fuel and of the products of combustion, the heat-generating power of the former, and the specific heat of the latter.

The specific heat of the products of combustion are, at constant pressure, and for equal weights:

TABLE XXX.

SPECIFIC HEATS OF PRODUCTS OF COMBUSTION.—(REGNAULT.)

(*Water* = 1. *Pressure constant.*)

Air	0.2374
Oxygen	0.2175
Nitrogen	0.2438
Steam	0.4805
Carbonic acid	0.2164

The proportions in which these substances occur in the products of combustion being known, the mean specific heat of all may be determined; and the total heat of combustion of one pound of fuel being divided by the product of this weight by this mean specific heat, *the quotient is the probable temperature of the furnace gases.*

Rankine gives the result of this calculation, in cases where carbon alone is burned with undiluted air, and diluted with one-half and with equal weight of additional air respectively, 4,580°, 3,215°, and 2,440° Fahr., equal to 2,627°, 1,824°, and 1,338° Cent.

Olefiant gas, similarly treated, should give temperatures of 5,050°, 3,515°, and 2,710° Fahr.; or, 2,788°, 1,953°, and 1,488° Cent.

The mean specific heat of the products of combustion is practically equal to the specific heat of air.

The following are the specific heats given by Rankine:

SPECIFIC HEAT UNDER CONSTANT PRESSURE:

Carbonic acid gas	0.217
Steam	0.475
Nitrogen, probably	0 245
Air	0.238
Ashes, probably about	0.200

By using these data, the above results are thus obtained for the two extreme cases of *pure carbon* and *olefiant gas*, burned respectively in air; British units are used:

	CARBON.	OLEFIANT GAS.
Total heat of combustion per pound	14,500	21,300
Weight of products of combustion in air, undiluted	13 lbs.	16.43 lbs.
Their mean specific heat	0.237	0.257
Specific heat × weight	3.08	4.22
Elevation of temperature, if undiluted	4,580°	5,050°
If diluted with air = ½ air for combustion.		
Weight per lb. of fuel	19.	24.2
Mean specific heat	0.237	0.25
Specific heat × weight	4.51	6.06
Elevation of temperature	3,215°	3,515°
If diluted with air = air for combustion.		
Weight per lb. fuel	25.	31.86
Mean specific heat	0.238	0.248
Specific heat × weight	5.94	7.9
Elevation of temperature	2,440°	2,710°

For wet fuel, like sawdust, or spent tan from the leach, the Author has made the following estimation in one actual case where the fuel consists of 45 per cent. woody fibre, and 55 per cent. of water.

Taking the available heat per pound of the dry portion at 6,480 British thermal units, each pound of wet fuel yields 2,916 units of heat. Of this, 531.6 are absorbed in the evaporation of the 55 per cent. of water, leaving 2,384.4 units to raise the temperature of the products of combustion. Of these there are, as a minimum, 3.7 pounds, having a mean specific heat of about 0.287.

The elevation of temperature is therefore 2,245.3° Fahr., and adding the mean temperature of the atmosphere, 74°, the mean temperature of furnace, assuming no dilution with unused air, and no losses, would have been about 2,320°, Fahr. (1,271° Cent.). Losing 2½ per cent. by radiation and conduction, etc., the actual temperature was 2,260° Fahr. (1,238° Cent.).

The temperature of chimney flue was found by experiment to have been 544°. The furnace gases were therefore cooled 2260° − 544° = 1716° Fahr. (937° Cent.) by the loss of the heat given up to the boiler. This is equivalent to 1716 × 0.287 = 492.5 British heat units per pound of gas, and to 4,049.4 units per pound of ligneous material in the fuel.

The "equivalent evaporation," from and at 212°, is 4049.4 ÷ 966.6 = 4.18 pounds of water. The actual evaporation was equivalent to 4.24 pounds, and the difference—less than one per cent. of the total—represents losses and errors of calculation.

The actual existing temperature of furnace can be also thus estimated. The available heat per pound of fuel, including water, has been given at 2,916 British thermal units. Of this $\frac{531.6}{2916} = 0.182$ passed off with vapor, and was not useful in raising the temperature of either the furnace or the chimney. Hence, of all heat liberated, 1.00 − 0.182 = 0.818 was efficient in elevating the temperature of furnace, and 0.37 − 0.182 = 0.188 was effective in producing the observed temperature, 544° Fahr., of chimney. Then, since the same quantity of gas passes at both places, the temperature of furnace was $\left(\frac{0.818}{0.188} \times 470\right) + 74° = 2119°$ Fahr. To this is to be added the slight loss of temperature *en route* between furnace and chimney by conduction and radiation, which may make the figure very nearly 2,260° Fahr. as above.

166. The Rate of Combustion is determined principally by the quantity of air supplied. The amount of coal burned per square foot of grate with chimney draught varies very nearly with the square root of the height of the chimney, and has been found by the Author, ordinarily to be very nearly

$$W = 2\sqrt{H} - 1, \quad \text{or} \quad W' = 17\sqrt{H'} - 0.5,$$

where W and W' are weights of fuel burned per hour per square foot of grate, and on the square metre, in pounds and

kilogrammes, and H and H' are the heights of chimney in feet and metres.

A chimney 64 feet or 19½ metres high, will, for example, under favorable conditions, usually support combustion of 15 pounds of coal per square foot of grate, or of 73 kilogrammes per square metre. The weight of combustible which may be burned in any unit of time may be calculated approximately by dividing the weight of air which can be supplied in that time, by its proportion to weight of fuel, as determined in the preceding paragraphs. In exceptional cases there is sometimes a large excess of air, and sometimes a considerable deficiency. In such instances, direct experiment only can determine the amount of fuel burned.

167. The Efficiency of the Furnace, considered as a heat-utilizing apparatus, is determined by the temperature of furnace gases, by the thoroughness with which complete combustion is secured, and with which losses of fuel and of heat are prevented. It is measured by the ratio of the amount of the total available heat of the fuel to that of the heat actually utilized. This efficiency is rarely so high as 80 per cent., and frequently falls to 50 per cent.

In all cases, efficiency is to be studied, in applications of heat, in two parts: (1) the efficiency of the heat-generating and absorbing apparatus, *i. e.*, the furnace; (2) the efficiency of the heat-utilizing apparatus and methods, as the steam boiler, the heating chamber of the reverberatory furnace, or such other heat-absorbing arrangement as may be adopted.

(1.) The efficiency of the furnace is represented by

$$E = \frac{T_1 - T_2}{T_1 - T_3}$$

in which E is the ratio of the heat rendered available to heat developed; T_1, T_2, T_3, are the temperatures of furnace, of chimney, and of external air. For examples, in two actual cases, T_1, T_2, T_3, were, 2,118° F., 544° F., and 74° F., or 1,176°, 302°, and 41° C. for the first case, and 919°, 452°, 86.5° F.,

or 510°, 251°, and 48° C. for the second case. The values of the efficiencies of the two kinds of apparatus were

$$\frac{2118° - 544°}{2118 - 74} = 0.77; \text{ and } \frac{919° - 452°}{919° - 86.5°} = 0.56;$$

or for Centigrade degrees,

$$\frac{1176° - 302°}{1176° - 41°} = 0.77; \text{ and } \frac{510° - 251°}{510° - 48°} = 0.56;$$

the first being nearly 40 per cent. higher than the second. A certain change of fuel would have given the first a maximum temperature of 2,644° F., 1,451° C., and would have raised its efficiency to

$$\frac{2644° - 544°}{2644 - 74°} = 0.81,$$

or

$$\frac{1451° - 279°}{1467° - 41°} = 0.81.$$

(2.) The efficiency of the heat-absorbing apparatus is dependent upon the character and proportion, and is not treated here. The highest efficiency in heat production is secured by perfect combustion with the least practicable air supply, thus obtaining the highest possible resulting temperature.

A large part of the heat produced by combustion of fuel is expended in producing chimney draught. This is not available for producing any other useful effects.

The amount of heat thus expended varies with the nature of the products of combustion, and the use to which the heat is to be applied. In all cases the heat thus discharged is wasted.

The temperature of the products of combustion cannot usually be reduced much below about 600° F., or 315° C.

Watts gives the loss in two typical cases of combustion of

carbon and of hydrogen in twice as much air as is necessary for their conversion into carbonic acid and water vapor:

	Parts by weight, products of combustion.	Quantity of heat = 1° in temperature of products.		Temperature of products.		Metric Heat units.
Carbon... 1 =	24.22	5.735245	×	315° C.	=	1807
Hydrogen. 1 =	80.56	19.765260	×	315° C.	=	6009

This loss is greater as the temperature at which the products of combustion pass to the chimney is higher. The minimum consumption of heat in producing draught by a chimney is about one-fourth of the heat generated.

If perfect combustion could be effected with no more air than is needed for perfect combustion, this loss of heat could be reduced one half.

By means of a forced draught, the economy of heat is increased, as the products of combustion when even far below 315° Cent. (600° Fahr.), can then be employed for heating.

168. To secure the highest efficiency of the furnace, good fuel should be selected; perfect combustion should be, as far as possible, secured by maintaining an ample supply of air, without excess; and by providing against abstraction of heat before oxidation is completed. The temperature of fire should then be the highest attainable, if complete intermixture of the combustible with the supporter of combustion is secured. The gaseous products should finally be as completely deprived of their heat as possible, before being discharged into the atmosphere.

In steam boilers, the latter requisite is secured by large area of heating surface, and by proper provision for taking off the gases at the coolest part of the boiler.

In metallurgical apparatus, efficiency is secured by utilizing heat which would be otherwise wasted, by heating incoming air, or the fuel, the ores, or the flux.

The most perfect combustion, and the most thorough utilization of the heat of the products of combustion, is obtained, in practice, in properly designed gas furnaces, where correct proportions of air and combustible gas can most readily be obtained, and perfect intermixture can be secured.

The mineral oils, and liquid fuels generally, promise excellent results when satisfactory methods shall have been found to secure the conditions of perfect combustion.

169. Each form of fuel, solid, liquid, and gaseous, is specially adapted to particular purposes; and, in selection, the engineer and metallurgist should carefully examine all of the circumstances of the case under consideration, in order to determine from which of these classes the fuel required should be selected; and, this choice having been made, he will next select that *quality* which best fulfills the requirements of the case.

TABLE XXXI.

COMPOSITION OF COMBUSTIBLES, CARBON TAKEN AS 100.

	CARBON.	HYDROGEN.	OXYGEN.
Wood	100	12.48	83.07
Peat	100	9.85	55.67
Lignite	100	8.37	42.42
Bituminous Coal	100	6.12	21.23
Anthracite Coal	100	2.84	1.74

170. Coal, whether anthracite or bituminous, is a fossil of vegetable origin. It is always associated with some earthy matter, and the latter is sometimes present in such quantities as to destroy the value of the coal as a fuel.

Coal is sometimes found so slightly altered as to differ but little, in chemical composition and in physical structure, from recent vegetable substances; and, in other cases, it is so thoroughly changed as to have become, in all but its chemical constitution, a mineral. Some of the more completely fossilized bituminous coal breaks into cubic and rhomboidal fragments, but the anthracite exhibits little or no traces of crystallization.

Chemical examination shows coal, as already indicated, to be composed of both organic and inorganic matter. The former is purely vegetable, and the latter consists of earthy matter above which the ligneous portions once grew.

Destructive distillation resolves the organic matter into

its invariable ultimate constituents, carbon, hydrogen, and oxygen, which come from the retort as solid carbon, or coke, liquid tar, gaseous ammonia, benzole, naphtha, paraffine, illuminating gas, sulphurous acid, and other substances, in various proportions. The inorganic portion is left as an ash when the fuel is burned. It consists usually of silicates in varying proportions.

171. The various fossil fuels having had a common origin, and being all more or less decomposed and mechanically altered vegetable matter, are found to exist in all states intermediate between that of recent vegetation and that of completely mineralized graphitic anthracite.

Their classification is, therefore, an arbitrary one, and it frequently happens that a particular species of coal lies so exactly between two classes, as to make it difficult to determine to which it should be assigned.

The anthracites are found among the older carboniferous strata; the bituminous coals come from the secondary; and the softest and least altered varieties from the tertiary formations.

The following, representing approximately the gradual change of composition as fossilization effects the alteration of woody fibre, is given by Dr. Wagner:

TABLE XXXII.

CHANGE OF COMPOSITION OF FOSSIL FUELS.

	CARBON.	HYDROGEN.	OXYGEN.
Cellulose	52.65	5.25	42.10
Peat	60.44	5.96	33.60
Lignite	66.96	5.27	27.76
" (earthy brown coal)	74.20	5.89	19.90
Coal (secondary)	76.18	5.64	18.07
" "	90.50	5.05	4.40
Anthracite	92.85	3.96	3.19

In the above analyses, earthy matter is excluded.

172. Anthracite Coal, called sometimes *glance*, and sometimes *blind* or *stone coal*, consists of carbon and inorganic sub-

stances, and is usually free from hydrocarbons. Some varieties are thoroughly mineralized and have become graphitic. The ordinary varieties of good anthracite are hard, compact, lustrous, and sometimes iridescent. The color is intermediate between jet black and that of plumbago.

It is amorphous and somewhat vitreous in structure, the hardest varieties falling to pieces when suddenly heated, and sometimes breaking up into very small fragments, thus causing considerable loss even when carefully "fired." It sometimes gives out a ringing sound when struck. It is a strong, dense coal, its specific gravity ranging from 1.4 to 1.6. It has a high calorific value.

It burns without smoke and without flame unless containing moisture, the vapor of which produces a yellow flame of comparatively low temperature. It kindles slowly and with difficulty; and, once kindled, requires to be carefully and skilfully managed to secure economic efficiency.

A representative variety has a specific gravity 1.55, and contains, exclusive of ash, carbon, 94 per cent., hydrogen and oxygen (moisture) 6 per cent. Of the latter, 2½ per cent. is hygroscopic, but is held with great tenacity.

The percentage of ash varies greatly, even in the same variety, and in specimens from the same bed. It may be estimated, as an average, at above ten per cent., while the total loss in ash, fine coal, and clinker will be likely sometimes to reach double that proportion in ordinary furnaces. When selecting anthracite it is necessary to keep this fact carefully in mind. Twenty-four samples of anthracite from Pennsylvania, analyzed by Britton, gave as a mean

Carbon	91.05
Volatile matter	3.45
Moisture	1.34
Ash	4.16
	100.00

There was included in the above, sulphur, 0.240, phosphorus, 0.013.

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A variety of this class of coals, similar in composition, but differing from the typical anthracite above described in structure, has been sometimes called *semi-anthracite.*

It does not exhibit the conchoidal fracture of the latter, but is somewhat lamellar, and is marked by fine joints or planes of cleavage. It crumbles readily, and has less density than the preceding.

One method of distinguishing good examples of the two varieties is found in the fact that the latter, when just fractured, soils the hand, while the former does not. The latter variety kindles quite readily and burns freely.

An example of this coal contained, in one hundred parts, carbon, 90; hydrogen and oxygen, 1.5; ash, 8.5.

173. The Bituminous Coals are sometimes divided into three classes.

Dry Bituminous Coal contains about 75 per cent. of carbon, 5 per cent. hydrogen, and 4 per cent. oxygen. That part of the hydrogen which is combined with carbon is capable of adding to the heat-giving power of the coal. This coal is lighter than anthracite, its specific gravity being about 1.3. Its color is black or nearly black, and its lustre resinous; it is moderately hard, and burns freely. Its structure is weak, brittle and splintery, fine-grained, and of uneven surface. It kindles with less difficulty than any variety of anthracite, but less readily than the bituminous coal to be described. It burns with a moderate flame, and gives off little or no smoke.

Bituminous Caking Coal contains sometimes as little as 60 per cent. of free carbon, and the maximum proportion is, perhaps, 70 per cent. It contains 5 or 6 per cent. each, of oxygen and hydrogen, and the remaining portion, amounting sometimes to 30 per cent., is incombustible. Its specific gravity is about 1.25. It is moderately compact; its fracture is uneven, but not splintery; its color is a less decided black than the preceding, and its lustre is more resinous. When heated it breaks into small fragments if the proportion of bitumen is insufficient to cause it to cohere before becoming thoroughly softened, but afterward, as it becomes more highly heated, the pieces become

pasty and adherent, and the whole mass becomes compact and hard as the gaseous constituents are expelled by heat.

This coal, ignited in air, burns with a yellowish flame and very irregularly unless kept continually stirred to prevent agglomeration and consequent checking of the draught. It cannot be successfully used, therefore, when great heat is required. It is valuable for the manufacture of gas and of coke, and can be used in small grates where but moderate heat is obtained.

Long Flaming Bituminous Coal is quite similar to the preceding, differing chemically in composition and containing a larger proportion of oxygen. It burns with a long flame, and has a strong tendency to produce smoke. Some varieties cake like the preceding, others do not; but all ignite readily and burn freely, consuming rapidly.

There are many varieties of coal in each of the above-named classes, the gradation being sometimes marked and sometimes barely distinguishable.

174. American Anthracites have been found, by experiments made under the direction of the United States Navy Department, to have a mean evaporative efficiency, in marine boilers, of 8.9 pounds of water evaporated from 212° Fahr. (100° Cent.) per pound of coal. The bituminous coals of the United States were found to evaporate an average of 9.9 pounds of water per pound of fuel, under similar conditions. The average efficiency of British coals is given by Bourne at about 8.7. American anthracites evaporated 10.69 pounds of water per pound of combustible matter contained in the fuels, and the bituminous coals 10.84, from 212° Fahr.*

These results are practically identical for the two kinds of coal; but the average of the best known varieties gives a difference which is, with such good varieties, in favor of anthracite.

175. Lignite, or *Brown Coal*, is of more recent and of more incomplete formation than the bituminous coals, and occupies a position intermediate between the true coals and

* See American Institute Reports; Tests of Steam Boilers, 1874.

peat. It contains from 30 to 60 per cent. of carbon, 5 or 8 per cent. of hydrogen, and 20 to 25 per cent. of oxygen. It is very light when pure, having, according to Regnault, a specific gravity of from 1.10 to 1.25. The heavier varieties contain much compact earthy matter.

Lignite is found in tertiary geological formations. It is brown in color, has the woody structure well defined, and is usually lustreless. Where it approaches the bituminous coals in age, it also approximates to them in structure and other characteristics. It frequently contains considerable moisture, which can only be removed by high temperature or by long seasoning, and the lignite, once dried, must be carefully preserved in dry situations if not used at once, as it re-absorbs moisture with great avidity.

When thoroughly dry it kindles readily, burns freely, and is consumed rapidly. It is not usually considered a valuable kind of fuel. It occupies considerably more space, weight for weight, than the true coals, burns, as an average, a third more rapidly, and its evaporation of water, per pound of fuel, is about 25 per cent. less. To obtain maximum evaporative efficiency a slow rate of combustion is found most effective.

176. **Peat,** sometimes called *Turf*, is obtained from bogs and swampy places. It consists of the interlaced and slightly decayed roots of vegetation, which, although buried under a superincumbent mass of similar material and mingled with some earthy matter, retains its ligneous structure and nearly all the chemical characteristics of unaltered vegetable matter. Submitted to the great pressure and the warmth which have for ages acted upon the coal beds, it would also probably become coal.

Dried in the air, it, like the lignites, retains moisture persistently, and is usually found to contain 30 per cent. after drying. After completely removing all water, an average specimen would contain about 60 per cent. of carbon, 5 to 10 per cent. hydrogen, and 30 or 40 per cent. of oxygen. The ash varies very greatly, sometimes being as little as 5, and, in other cases, as high as 25 per cent.

A pound of wood charcoal has nearly the same value as a fuel as 1.66 pounds of peat of average quality.

Peat is frequently used in large quantities for heating purposes, and attempts have been made, with encouraging results, to use it in metallurgical operations.

When to be thus used, it is cut from the bog with sharp spades, ground up in a machine specially designed for the purpose, and dried by spreading it where it can have full exposure to the sun and air.

It is frequently compressed by machinery until its density approaches that of the lighter coals, and it is used in blocks of such size as are found best suited to the particular purpose for which it is prepared.

Its charcoal makes excellent fuel for use in working steel and welding iron. It is frequently found to be a very excellent fuel for other purposes, and is extensively used in some localities. Its specific gravity is usually about 0.5.

177. Wood, thoroughly seasoned, still contains about 20 per cent. of moisture.

The moisture being completely driven off by high temperature, there is left about 50 per cent. carbon, and combined oxygen and hydrogen compose the remainder, in very nearly the proportions which form water. The pines and firs contain turpentine, and other woods contain frequently a minute proportion of hydrocarbons peculiar to themselves.

The proportion of ash varies from about 0.5 per cent. to 5 per cent. The woods all evaporate very nearly the same weight of water per pound of fuel. The lighter woods take fire most readily and burn most rapidly; the denser varieties give the most steady heat and burn longest.

Where radiated heat is desired the hard woods are much the most efficient.

The seasoning of wood has been described in that part of this work which treats of timber.

Thorough seasoning in the open air requires from six months to a year, and is the only method generally adopted for wood intended to be used as fuel. One cord of hard

wood, such as is used on the Northern lakes of the United States, is said to be equal in calorific power to one ton of anthracite coal of medium quality. One cord of soft wood, such as is used by steamers on Western rivers, is equal in heating power to 960 lbs. (436 kilogrammes) or 12 bushels (423 cubic decimitres) of Pittsburgh coal. One cord of well seasoned yellow pine is equivalent to 1½ tons (500 kilogrammes) of good coal.

178. **Coke** is made from bituminous coal by subjecting it to such high temperature as to deprive it of its volatile constituents.

The presence of moisture in some of the coals largely reduces their heating power. The bituminous matter causes them to fuse and to form a coherent mass, and, by thus preventing the passage of air, destroys their efficiency for many purposes. The presence of sulphur and of deleterious volatile substances in many coals also precludes their application to the reduction of iron ores, and destroys their value for other metallurgical purposes. All of these volatile materials being driven off by heat, a mass of fixed carbon containing only earthly impurities remains, which "coke" constitutes the fuel with which some of the most extensive and important metallurgical industries are conducted. These volatile matters are sometimes utilized, but are generally wasted, except where the coke is considered a secondary product, as in the manufacture of illuminating gas.

Coking is carried on by either of these methods—in open heaps, in coke ovens, or in retorts.

The first method is extremely wasteful and is rarely practiced; the second is more economical; and the third is the best where gas is manufactured, and is the only one practiced in that case. The second method is that generally adopted where the coke is the primary product, as, although not as economical as the last, it produces a strong coke which is much better adapted for use in furnaces than that afforded by the last method, which, although allowing of the complete separation and collection of the liquid and gaseous products of distilla-

tion, yields a coke which has too little density and strength to make it a valuable fuel.

Coke made in ovens is usually of a dark gray color, porous, hard, and brittle. The best gives out a slight ringing sound when struck, and has something of the metallic lustre. It makes an intense, clear fire, and it should not be forced so as to injure either the boiler or the grate by burning the iron. Where the coals contain sulphur but are free from moisture, provision should be made for the passage of a supply of steam through the oven. This will give up its oxygen to the metal with which the sulphur is combined, and the hydrogen, uniting with the latter, forms sulphuretted hydrogen. The coke is thus left comparatively free from the noxious ingredient, and as this is usually the only constituent of bituminous coal which injuriously affects iron, the coke is a better fuel than the coal from which it is made.

Various coals yield from ·33 per cent. to 90 per cent. of their weight in coke. The latter containing all the ash, the percentage of ash in coke will be higher than in the coal from which it is prepared. Coke has a strong tendency to absorb moisture, and may, when unprotected from dampness, condense 15 or 20 per cent. of its own weight within its pores.

Coke should be carefully washed when it has been made from an earthy or pyritous coal. This process is practiced with French cokes, and is found greatly to improve them. The expense of subsequent drying is, however, considerable.

Calvert's process for the removal of sulphur compounds consists in the addition of salt to the coal in the coking furnace, which, by double decomposition, produces volatile compounds of sulphur and chlorine. Coke supplied to British iron makers contains frequently from 1 to 1.50 per cent. sulphur.

American coals are generally less contaminated with this seriously injurious element than are the British. Many cokes contain 15 per cent. ash and 1 or even 2 per cent. sulphur; while others contain but 3 to 5 per cent. ash and $\frac{1}{10}$ per cent. sulphur. This is the principal fuel used in metallurgy.

An average of forty-nine samples of Connellsville coke analyzed by Britton contained:

Carbon	87.456
Moisture	0.490
Ash	11.332
Sulphur	0.693
Phosphorus	0.013
Loss	0.016
	100.00

Its ash contained:

Silica	47.90
Alumina	47.76
Oxide of iron	1.43
Lime	1.48
Magnesia	0.53
Sulphur	trace
Phosphorus	0.09
Alkalies	0.49
Loss	0.32
	100.00

179. **Charcoal** has the same relation to wood that coke has to bituminous coals.

It is made from all kinds of wood, hard wood charcoal being the best for fuel. Wood of about twenty years of age is preferred, and should be charred before decay has commenced. The methods of preparation are substantially the same, and the chemical constitution of the product is very similar, although its physical characteristics are quite different.

Charcoal prepared by charring in heaps seldom amounts to more than 20 per cent. of the total weight of wood used; carelessness in conducting the process may reduce the weight of product far below even that figure. A considerable loss is unavoidable, since the charring of one portion must be effected by the heat obtained from the combustion of another part of the wood. Sound wood is selected, cut in billets four or five feet in length, and, when large, split into sticks of from three to six inches in thickness. It is best to assort the

wood, placing each kind in piles by itself. In making up the heap the ground is cleared, a stake is set at the centre of the cleared space, and a layer of wood is put down with all the sticks laid radially, and the interstices filled with smaller sticks. On this layer the rest of the wood is piled on end, beginning by leaning sticks against the centre stake. The whole is finally covered with another closely packed layer, which, in turn, is completely covered with sods.

A central hole is left and also an uncovered ring around the base five or six inches high, for the air supply. One or two horizontal passages left in the pile conduct the gases to the centre, where they rise, passing out at the hole made by pulling out the centre stake before firing the pile.

The fire being started and actively burning, all openings are closed, and combustion is perfectly controlled by altering their number and position. The condition of the fire is indicated by the color of the smoke, which should be black and thick; when it is light and bluish the draft should be more completely checked. The work is finished when the wood at the exterior of the pile is found charred. All openings are then closed, and the fire is thus extinguished. The pile can be usually opened on the following day, and the removal of charcoal begun. So crude a process is very liable to excessive losses from the difficulty experienced in adjusting the supply of air, and in conducting the heated products of combustion to precisely the right points, and in precisely the right proportions to secure maximum efficiency.

The presence of moisture in wood is productive of loss by giving rise to the formation of carbonic oxide and of new hydrocarbons. They carry off carbon which would otherwise have been left in the solid state as so much charcoal.

Dry wood, charred in a retort, yields as a maximum about 30 per cent. of its weight in charcoal. Of the carbon originally contained in wood, therefore, by the first method of charring, not above one-half may be expected to be obtained as charcoal, while, by the last method, three-quarters may be obtained by skilful management. The latter process requires

the expenditure of about one-eighth of the weight of wood charred, for the production of the heat demanded by that process. It, therefore, yields a net amount in charcoal, of about thirty per cent. of the total weight of wood used. The wood which is used for fuel, however, may be of less value than that charged into the retort. Peat charcoal is sometimes made by similar methods, but is little used.

Charcoal has been successfully prepared by the action of highly superheated steam upon wood, as proposed by M. Violette.

Karsten, Stolze, Winkler, and others, have found that the quantity and quality of charcoal are largely influenced by the temperature of distillation.

Wood heated to 300° Fahr. (150° Cent.) for a considerable length of time, loses 60 per cent. or more of its weight. If heated only to slightly above 212° Fahr. (100° Cent.), the loss is but from 50 to 55 per cent. The residue resembles charcoal, but, in each case, it retains some volatile matter which may be driven off by higher temperatures. Karsten found that, by rapid charring at high temperatures, he obtained, as an average, about 15 per cent. charcoal in one series of experiments; while, by slowly charring the same woods at a low temperature, the percentage obtained averaged about 25 per cent.

In making charcoal in retorts, on a large scale, the following is given as the character and distribution of the carbon of the product:

Charcoal	30.00
Carbon in acetic acid	0.50
" " tar	6.00
" " hydrocarbons and oxides	3.50
" used as fuel in the process	5.00
Total carbon in 100 parts wood	45.00

The combustibility of charcoal is greater when prepared at a low, than when prepared at a high temperature, as is shown by the following approximate tabular statement:

TABLE XXXIII.

IGNITION OF CHARCOAL.

Temperature of preparation.		*Temperature of ignition.*	
3,000° Fahr.	1,650° Cent.	2,500° Fahr.	1,371° Cent.
2,500° "	1,371° "	1,300° "	705° "
2,000° "	1,093° "	1,100° "	593° "
1,500° "	815° "	900° "	482° "
1,000° "	538° "	800° "	427° "
500° "	260° "	650° "	332° "

In the accompanying diagram (Fig. 53), the vertical scale is one of temperatures of preparation, and the horizontal is one of temperatures of ignition; and the curve shown contains the points of correspondence as given in the table. It will be seen that the curve is apparently nearly hyperbolic.

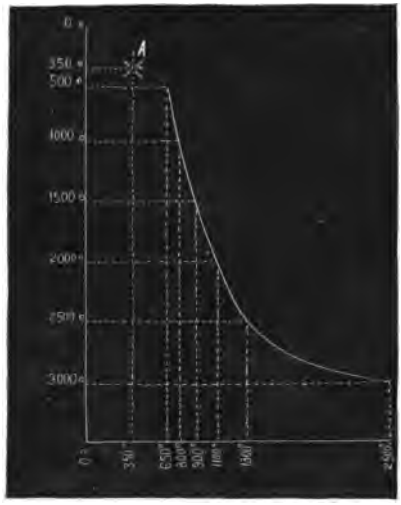

FIG. 53.—IGNITION OF CHARCOAL.

The lowest temperature of preparation was 500° Fahr. (260° Cent.); but it is seen that, at 350° (177° Cent.), the temperature of steam under a pressure of over 125 lbs. per square inch (8.75 kilogrammes per square centimetre), the temperature of preparation and of ignition cannot coincide unless some marked change of law should occur at this low temperature, carrying the curve, which here represents that law, abruptly inward to reach the point *A*, and it is thus indicated that wood is not likely to be fired by heated steam pipes, even when charred by contact with them.

Ignition by contact with heated steam-pipes may nevertheless occur if greasy substances, and perhaps when pitchy substances, are present.

Charcoal absorbs gases and vapors with great avidity, and should be carefully enclosed, when intended to be kept some time before using, in order to prevent serious injury from this cause. The lower the temperature at which carbonization is effected, the greater the power exhibited by the charcoal, of absorbing gases and vapors. This is exhibited by the following tabular statement of results deduced from M. Violette's experiments:

TABLE XXXIV.

ABSORPTIVE POWER OF CHARCOAL.

Temperature of preparation.		*Percentage of vapor absorbed.*
2,732° Fahr.	1,500° Cent.	2.254
2,000° "	1,093° "	4.450
1,500° "	815° "	4.700
750° "	399° "	4.900
600° "	316° "	5.500
500° "	260° "	6.836
400° "	204° "	9.750
300° "	149° "	20.860

The Density of Charcoal depends largely upon the nature of the wood from which it is made. Its specific gravity is given by Hassenfratz, as follows:

TABLE XXXV.

SPECIFIC GRAVITY OF CHARCOAL.

Birch	0.203
Ash	0.200
Beech	0.183
Elm	0.180
Red Pine	0.176
Maple	0.164
Oak	0.155
Pear	0.152
Alder	0.134

The apparent density of the mass is, however, far less than the real density, as determined by Violette, after expelling the air from its pores. Violette found the true density of charcoal of black alder to vary from 1.5 to 2.0; the former

being that of charcoal prepared at 300° Fahr. (150° Cent.), and the latter at above 3,000° Fahr. (1,650° Cent.)

Good charcoal is black, with a high lustre, and has a conchoidal fracture. It is quite strong, and the best qualities ring when struck, although less than good coke. It burns without flame or smoke, and radiates heat strongly. It should not soil the hands.

Charcoal and coke both make an intense, clear fire, and with a forced draught, giving a small air supply, afford an extremely high temperature which is liable to injure the grates or anything metallic which may be subjected to its action.

180. Pulverized Fuel, or *Dust-Fuel,* is sometimes used in special metallurgical processes.

In the use of this form of fuel, special arrangements become necessary to secure thorough intermixture of the fuel with the supporter of combustion, in order to effect complete oxidation. The fuel itself is sometimes prepared by pulverizing coal, or other combustibles; and sometimes it is obtained from the large deposits of "slack," "breeze," or coal dust which are found wherever coal in large quantities is subjected to attrition. It is sometimes burned on a very fine grate, the requisite supply of air being secured by the use of a blast beneath the grate.

One of the most successful methods is that pursued by Whelpley and Storer, and by Crampton. In this process a stream of mingled dust-fuel and air is driven into the furnace where combustion takes place, the quantity of fuel and of air being capable of adjustment in such a manner as to secure the most perfect combustion. This method has been applied successfully, not only in the production of heat simply, but also in the reduction of metals from their ores. The facility with which an oxidizing, or a reducing flame, may be produced at will is the great merit of the process in the latter application. Its advantage for heating purposes lies in the power which it gives of utilizing a fuel which would have otherwise no value. In making "muck-bar," an economy over that attained with coal, of above 20 per cent. has been reported to have been effected by the use of this process

and fuel. The saving occurred in reduction of waste of metal, as well as in simple economy of fuel. At the United States Armory, at Springfield, Massachusetts, 6.6 pounds or kilogrammes of fuel were consumed per pound or kilogramme of iron heated to the welding heat, where 16 had been required by the old process.*

181. Liquid Fuels have been used to a limited extent. The liquids best adapted for use as fuel are the mineral oils. They yield an intense heat; the products of combustion, as well as the fuels themselves, are comparatively free from deleterious elements, and the temperatures obtained by their use are generally easily regulated, when they are burned in manageable quantities. Their tendency is to give off combustible gases, which may cause serious explosions; and this fact, but especially the difficulty met with in uniformly distributing the oil, and in properly supplying it with air for its combustion, have hitherto prevented the general use of these fuels, even where their comparatively high cost would not be a serious objection to their application.

Crude petroleum, on distillation, breaks up into a large number of hydrocarbon compounds, having boiling points varying from 32° Fahr. (0° Cent.) to 700° Fahr. (371° Cent.) as given by Van der Weyde. Its density is variable, but usually about 45° Beaumé, corresponding to a specific gravity of about 0.8, the gallon weighing 6.67 pounds, and the litre weighing 0.8 kilogramme. It contains by analysis: carbon, 84; hydrogen, 14; oxygen, 2. The latent heat of its vapor is about one-fifth that of steam, and its volume 25 cubic feet to the gallon of oil, or 0.2 cubic metre per litre.

The "creosote," or "dead oil," produced in gas making, is sometimes used as fuel. In experiments on board the British steamer *Retriever*, in 1868, where creosote was used for the generation of steam by what is called the Dorsett system, the evaporation was about 14 pounds or kilogrammes of water from a boiling point per pound or kilogramme of liquid fuel used, or nearly double the average obtained where coal was used in the same boiler.

* Report Lieut. H. Metcalf to Major Burton, Oct. 31st, 1873.

Dr. Paul, reporting these results, gives the theoretic evaporative power of the constituents of this fuel, in units in weight of water per unit of fuel, as follows: phenol, 12.25; cressol, 13.01; napthaline, 15.46; xylol, 16.59; cumol, 16.78; cymol, 16.94.

Capt. Selwyn, R. N., reported an evaporative power from boiling point of 16.77 parts water per part by weight of a liquid fuel which had a theoretical efficiency of 17.52 parts. In another instance, he gives the evaporation of 14.98 from the boiling point, by a fuel having a theoretical evaporative power of 17.5. Deville found oil from Oil Creek, Pennsylvania, to have a calorific value of 10,000 "calories," equivalent to the evaporation of 16.17 parts of water for one part by weight of oil. Of this 13⅓ per cent. was lost by the chimney, and by conduction and radiation. Some other oils give slightly higher figures.

Using this fuel, Eames has attained temperatures in the reverberatory heating furnace, according to Wurtz,* exceeding 3,300° Fahr. (1,816° Cent.). Iron plate made with this fuel from mixed scrap had a density (sp. gr.) of 7.7, a tenacity of 50,000 lbs. per square inch, or 3,500 kilogrammes per square centimetre of original area, and extended from 5 to 15 per cent., as tested by the Author; the iron was very hard, fine, and even in grain.

The furnace was heated in 45 minutes, with 22½ gallons (85.5 litres) of oil, and the piles of iron were well heated in about a half hour more. Eight tons (8,128 kilogrammes) of iron per day were heated and rolled from one furnace, and with a consumption of one-eighth its weight of oil.

Iron puddled by the Eames process was, according to Dr. Channing, of excellent quality; it was subject to slight loss by oxidation, and its cost was less than when made with coal.

Experiments made with liquid fuel in heating armor and ship plates, at Chatham Dockyard, in May, 1869, gave better results, where 705 pounds (320 kilogrammes) of oil were used

* *Engineering and Mining Journal*, Aug. 7, 1875, p. 124.

in heating a number of plates, preparatory to bending them, than where 3,300 pounds (1,500 kilogrammes) of coal was used for a similar lot.

This fuel was reported to require 34 cubic feet (0.963 cu. m.) of storage capacity per ton; while British coals, used in competing trials, required 43 cubic feet (1.228 cu. m.). The economy in storage thus amounted to above twenty per cent.

According to Wurtz, a barrel of crude petroleum has superior heating power to 1,280 pounds (580 kilogrammes) of the best bituminous coal, as applied to heating iron.

Experiments made by Engineer-in-Chief B. F. Isherwood, U. S. N., under the direction of the U. S. Navy Department, upon various systems of utilization of petroleum as a fuel, gave a maximum economy, over the use of anthracite, of 68 per cent. by Fisher's method of burning oil, and 38 per cent. by Foote's process of burning liquid and solid fuel together; he reports the failure of another method, in consequence of the obstruction of the tubes by deposition of solid carbon.

Value of Liquid Fuels.—Isherwood states the advantages attending the use of the mineral oils, which were the subject of his experiments, as follows:

(1.) A reduction of weight of fuel amounting to 40½ per cent.

(2.) A reduction in bulk of 36½ per cent.

(3.) A reduction in the number of firemen ("stokers") in the proportion of 4 to 1.

(4.) Prompt kindling of fires, and consequently the early attainment of the maximum temperature of furnaces.

(5.) The fire can, at any moment, be instantaneously extinguished.

Other advantages, unmentioned by him, are the uniformity of combustion and heating attainable, and the small proportion of ash. The disadvantages are given as follows:

(1.) Danger of explosions occurring by the taking fire of the vapors which are liable to arise from the fuel, and to escape from the tanks.

(2.) Loss of fuel by evaporation.

(3.) The unpleasant odors which distinguish these vapors.

(4.) The comparatively high price, which price would be rapidly augmented by any general introduction of the proposed application of the oils.*

Many other inventors, in the United States and in other countries, including Wyse, Field, Deville, and Blyth, have attempted the use of liquid fuels, but no permanent success seems to have attended their efforts. Where petroleums are obtainable at low prices, they are used to a limited extent as fuel; and their ultimate successful introduction may not be improbable.

182. Gaseous Fuels are used with marked success in some branches of metallurgical work, as well as in the generation of heat for ordinary purposes.

The advantages possessed by gaseous fuels are:

(1.) Convenience of management of temperature.

(2.) Freedom from liability to injure material with which the products of combustion may come in contact, and consequently, also, allowing the use of fuel of inferior quality as a source of the gas.

(3.) The facility with which thorough combustion may be secured.

(4.) The readiness with which the flame may be given either an oxidizing or a deoxidizing character.

(5.) In many cases, economy in expense of operation.

The disadvantages are:

(1.) Danger of explosions, when carelessly or unskilfully handled.

(2.) Expense of plant.

There have been many attempts to use gas as a fuel, upon

* This may be questioned, since recent explorations of oil deposits, especially of the United States, indicate an immense supply as immeasurable and probably nearly as inexhaustible as the coal fields.

a large scale, the most successful method being that adopted in the "Regenerative Gas Furnace."

In this furnace an effective method of generating combustible gases, and of obtaining their thorough intermixture with the supporter of combustion is secured; and the heat-generating apparatus is what is known among engineers as a regenerator, in which heat that would otherwise be carried to the chimney by the escaping gases, and wasted, is rendered available by transfer to the air and to the gaseous fuel, as they are about entering the furnace, where they are to combine. According to Dr. C. W. Siemens, taking the specific heat of iron at 0.114, and the welding heat at 2,700° Fahr. (1,482° Cent.), it would require $0.114 \times 2{,}700 = 308$ British heat units (77 calories) to heat 1 lb. (0.45 kilogramme) of iron. A pound of pure carbon develops 14,500 British heat units (3,625 calories), a pound (0.45 kilogramme) of common coal 12,000 (3,000 calories); and therefore 1 ton (1,016 kilogrammes) of coal should bring 39 tons (39,624 kilogrammes) of iron up to the welding point.

In an ordinary reheating furnace, a ton or a kilogramme of coal heats only 1⅔ tons or kilogrammes of iron, and therefore produces only one twenty-third of the maximum theoretical effect. In melting one ton or a kilogramme of steel in pots, 2½ tons or kilogrammes, of coke are consumed; and taking the melting point of steel at 3,600° Fahr. (1,982° Cent.), the specific heat at 0.119, it takes $0.119 \times 3{,}600 = 428$ British heat units (107 calories) to melt a pound (0.45 kilogramme) of steel; and taking the heat-producing power of common coke also at 12,000 British units (300 calories), a ton or a kilogramme of coke ought to be able to melt 28 tons or kilogrammes of steel.

The Sheffield pot steel-melting furnace therefore only utilizes one-seventieth of the theoretical heat developed in combustion.

183. The Siemens Furnace consists of three parts: the gas producer, the furnace proper, and the regenerator.

The *Gas Producer* (Fig. 54) is a chamber, *E H*, lined with fire-brick, with one side, *B*, inclined 45° to 60°, and of sufficient

capacity to contain a large mass of coal or other gas-producing fuel. The grate *C*, at the foot of the incline, is of comparatively small area, and in consequence of the limited supply of air which can pass through the bars, the fire is of

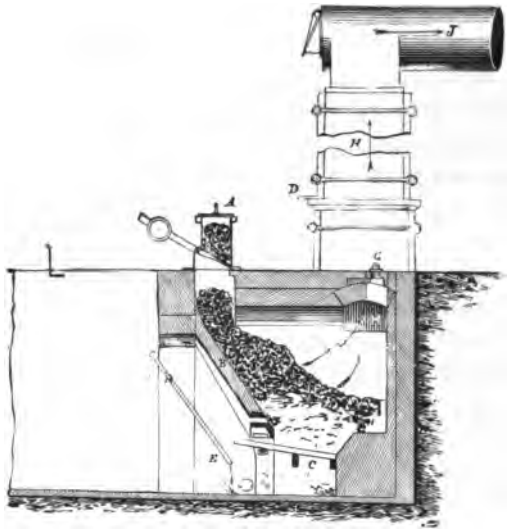

FIG. 54.—SIEMENS' GAS PRODUCER.

small extent, and is simply sufficient to distil the coal; while the carbon not carried off in the hydrocarbon products of distillation is not completely oxidized, but passes off with the combustible gases to the furnace, as carbonic oxide.

The Wilson Gas-Producer (Fig. 55) may be described as follows: It is about 8 feet external diameter, and 10 feet high, consisting of an iron casing lined with brick-work, without any grate bars. A box runs across the centre of the hearth, having tuyeres in its sides, and two doors are provided, one at each side the central tuyere, for removing ashes and clinkers.

The air is forced in by two small steam jets, each blowing down a taper pipe outside, as shown. The upper portion of the producer forms a kind of retort, with an annular flue communicating with a branch pipe, through which the gas

escapes. At the top there is a bell and hopper for charging the fuel.

The action of the producer is as follows: The interior is nearly full from top to bottom, of coal which rests on the

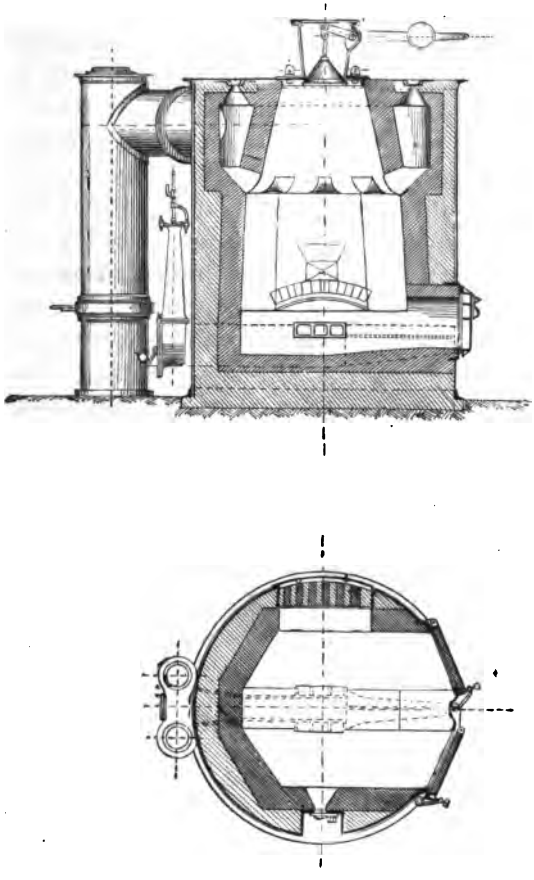

FIG. 55.—THE WILSON GAS PRODUCER.

solid hearth. Into the centre of this mass of fuel, near the hearth and as far as possible from the side walls, air and steam are injected from each side of the central tuyere, which communicates with the steam jet blowers outside.

A rapid combustion takes place in the vicinity of the tuyere, where the carbon is decomposed into carbonic oxide at a bright red heat, and with the hydrogen also decomposed from the steam passes upward and escapes by the outlet ports into the annular flue, surrounding the top portion of the chamber.

The coal is charged from time to time, as every half-hour, through the bell and hopper at the top, and the hydrocarbons are for the most part distilled in the retort portion, which is above the ports, and have to pass downward to escape, along with the carbonic oxide and hydrogen from the bottom. The top portion of the fuel is comparatively cool, because the hot gases from the bottom do not pass through it, and hence the distillation of the hydrocarbons is gradual and uniform—no eruptions of gas occurring just at the moment of charging. This conduces to regularity in the production of gas, and has the further advantage of causing a decomposition of the tar-laden gases in their passage downward, through a hot layer of fuel, so that they do not afterward readily deposit the tar. This producer consumes about double the fuel usually burned in producers having natural draught—about 25 or 30 pounds per square foot of grate.

Bituminous coal is generally used in the gas producers, and the composition of the gas obtained is given by Siemens, in one instance, as follows:

	VOLUMES.
Carbonic oxide	24.2
Hydrogen	8.2
Carburetted hydrogen	2.2
Carbonic acid	4.2
Nitrogen	61.2
	100.0

In some instances, anthracite coal has been used successfully, the gas producer yielding only carbonic oxide as the combustible constituent of its products.

The gas passes from the gas producers through cooling tubes, in which any moisture present may condense, to the regenerators and to the furnace, which it enters through a

number of openings, meeting the air which is similarly introduced, and combining with it over the bed of the furnace.

The size and number of openings for the entrance of the gas are determined by the character of the work to be done by the furnace, a large number of small openings causing prompt mixture of gases, rapid combustion, and a short flame of high temperature; while a small number of large openings gives less rapid combustion, and a longer and less intense flame.

The gases leaving the furnace are invariably of high temperature, but to save this heat, they are conducted through the regenerators on their way to the chimney.

The Regenerators (Fig. 56) are chambers lined with fire-bricks, and filled up with loosely stacked fire-bricks, so piled as to expose as much surface as possible to the gases which are led among them. These regenerators are worked in pairs. The hot gases, streaming through the mass of brick-work, give up their heat, and reach the chimney comparatively cool. When the temperature of one pair has been sufficiently elevated, by the passage through it of the products of combustion, the current of hot gas is turned through the second pair of regenerators, which are heated in turn.

The gases coming from the gas producer, and the air entering the furnace, both pass, in separate streams, through these heated masses of brick-work, and are thus raised to such a temperature that they enter into combination as soon as they meet and mingle in the furnace.

The escaping gases of combustion having heated the second pair of regenerators, and the entering gases having, at the same time, cooled the first pair, the currents are again changed; the hot gases passing through the first and again heating them, while the uncombined gases now pass separately through the second pair of regenerator chambers, and become highly heated while cooling the brick-work.

This alternation of currents takes place three or four times each hour; and the economical value of the regenerative process is found to be very great, where the refrigeration of the products of combustion is thoroughly performed. Where

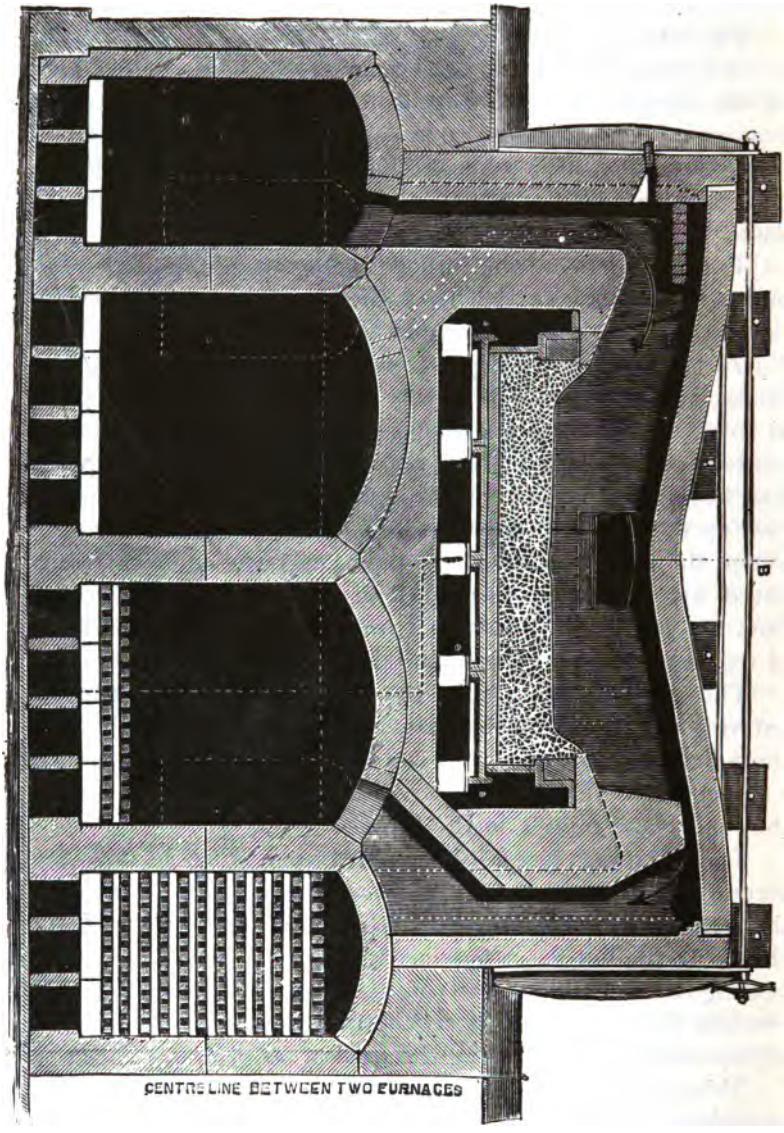

FIG. 56.—SIEMENS' REGENERATOR.

these furnaces are well designed, the products of combustion are sometimes reduced in temperature as low as 300° Fahr. (149° Cent.).

A special advantage of the gas furnace which is here described, arises from the circumstance that the most intense heat may be obtained without the strong draught needed in more common forms of furnace. The gases coming in contact with the metal upon the bed of the furnace are therefore free from the dust almost invariably carried over from the fuel in the latter, and which cuts away the brick-work, either by fluxing it, or by mechanical wear. The flame of the gas furnace is so pure that, unless fluxed or actually melted, the lining of the furnace may last an indefinite length of time.

The advantages also offered of being able to adjust the flame to any desired degree of length, intensity of heat, or of oxidizing or deoxidizing power, are frequently of greater importance than that just stated, or even that of economy of fuel. The maximum temperature attainable in the gas furnace, or in the furnace using pulverized fuel, where properly proportioned, is usually practically limited by the heat-resisting power of the furnace walls. The theoretical limit is at or near the temperature of 4,500° Fahr. (2,482° Cent.), at which point, the "point of dissociation," as it is called by Deville, is reached, and the action of chemical affinity is stopped by the intensity of heat repulsion.

184. Artificial Fuels, other than charcoal, coke, and gases, are occasionally used in the production of high temperatures.

They are prepared principally from refuse of natural fuels, which has but little value in its usual condition, but which, by special processes, is simply mixed with a small proportion of fuel of better quality, or of more manageable form, and is compressed by machinery into conveniently shaped blocks, called *briquettes.* This refuse is found in large quantities in the neighborhood of coal mines, and wherever coal is handled in considerable quantities.

The total loss in this form in mining and transportation amounts to from one-third to one-half. It is called, as has been before stated, *slack-coal.*

In the manufacture and transportation of coke and of charcoal, large quantities of refuse, called "breeze," accumulate; which, although very rich in combustible matter, cannot be utilized in the condition in which it is found, except by special contrivances. The sawdust which accumulates about saw-mills is another variety of combustible belonging to the same class; as is also spent tan-bark, from tanneries, and "bagasse," or refuse crushed sugar-cane.

These varieties of refuse combustible material usually have the character of the fuel already referred to as pulverized fuel, and may frequently be utilized by the methods described in Article 269.

Many methods have been devised, however, by which to fit them for use in furnaces which have been designed for more common, but more expensive, kinds of fuel.

They are most frequently mixed with some cohesive, and at the same time combustible substance, as coal tar. In districts abounding in mineral hydrocarbons, as in the neighborhood of the Caspian Sea, it has long been customary to mix them with clay, and thus to form a coherent and manageable fuel. The Norwegians have also long practiced their method of utilizing sawdust by mixing it with clay and vegetable tar, and moulding it into bricks of such size and shape as to be conveniently handled, and, at the same time, to burn freely and without waste. It has been often urged, and with some reason apparently, that for many purposes, a fuel made by careful mixture of dust-fuel with pitch or other combustible cementing material, is preferable to ordinary coal, in consequence of the greater convenience with which it can be stowed and handled.

A French method of utilizing waste fuels consists in thoroughly mixing, by grinding, charcoal dust from the kilns with charred peat, spent tan-bark and the proper proportion of tar or pitch to make a pasty, adhesive mass. This is moulded by machinery, and dried in the open air, and then finally baked in closed retorts at a low heat.

By an English process, dust coal and pitch have been made into a good fuel in quite a similar manner to that just

described. The proportion of tar or pitch required is from 5 to 16 per cent. of the total mass of fuel. In most cases, the volatile constituents of the manufactured fuel, as the naphthas, are driven off by kiln-drying, or by heating strongly in retorts.

There have been many varieties of grinding, moulding, and compressing machines designed and used in the manufacture of artificial fuels, but none require description here.

Dehaynin's compressed fuel is made by compacting the material in cylindrical pipes, resistance being secured by the friction encountered within the proper length of pipe; and it emerges as a cylindrical bar which is quite strong and solid, and is then broken into short lengths for the market. Ten tons (10,160 kilogrammes) per hour are reported to be made with 80 horse-power. The product is slightly heavier than coal, and is claimed to be its equal in calorific power. Two hundred thousand tons (203,200,000 kilogrammes) per year has been made by the inventor of this process.

185. Economy in Combustion of Fuels, where they are used simply in the production of high temperature, is so important a matter, except in those favored localities where the proximity of coal, or of peat beds, or of forests, renders its waste less objectionable, that the engineer should omit no precaution in the endeavor to secure their perfect utilization.

To secure the greatest economy, it is necessary to adopt a form of grate, which, while allowing a sufficient supply of air to pass through it to insure complete combustion, has such narrow air spaces as to prevent waste of small fragments, by falling through them.

The narrower the grate bars and the air spaces, the more readily can losses from this cause, and from obstruction of draught, be avoided. With a hot fire, however, the difficulties arising from the warping of the bars, become so great, that it is only by peculiar devices for interlocking and bracing them that their thickness can be reduced below about ⅞ of an inch at the top. Many such devices are now in use. In furnaces burning wet fuel, with an ash pit fire, fire-brick grate bars are used.

A certain amount of air must usually be allowed to enter the furnace above the grate, to consume those combustible gases which do not obtain the requisite supply of oxygen from below. The carbon, probably, in such cases, usually obtains its oxygen from below the grate, while the gaseous constituents of the fuel are consumed by the oxygen coming in above.

Chas. Wye Williams, who made most extended and careful experiments on combustion of fuel, recommended, for ordinary cases, where bituminous coal was burned, a cross area of passage, admitting air above the grate, of one square inch for each 900 pounds of coal burned per hour, or about one square centimetre for each 63 kilogrammes of fuel. This area should be made larger, proportionally, as the thickness of the bed of the fuel is increased, and as the proportion of hydrocarbons becomes greater.

Chilling the gases, before combustion is complete, should be carefully prevented; and comparatively cold surfaces, as those of a steam boiler, should not be placed too near the burning fuel. A large combustion chamber should, where possible, be provided, and more complete combustion may be expected in furnaces of large size, lined with fire-brick, and with arches of the same material, than in a furnace of small size where the fire is surrounded by chilling surfaces, as in a "fire-box steam boiler."

Finally, the greatest possible amount of heat being developed in combustion, careful provision should be made for completely utilizing that heat.

In a steam boiler this is accomplished by having large heating surfaces, and by so arranging the distribution of the adjacent currents of water and of hot gases that their difference of temperature shall be the greatest possible. The gases should enter the flues at that part of the boiler where the temperature is highest, and leave them at the point of lowest temperature. The feed water should enter as near as possible to the point where the gases pass off to the chimney, and should gradually circulate until evaporation is completed at, as

nearly as possible, that part of the boiler nearest to the point of entrance of the heated gases.

Where a small combustion chamber is unavoidably employed, as in locomotives, various expedients have been devised with the object of producing complete intermixture of gases before entering the tubes. The most common and most successful is a bridge-wall, sometimes depending from the crown sheet, but sometimes rising from the grate, and which, by the production of eddies in the passing current, causes a more thorough commingling of the combustible gases with the accompanying air. None of these devices seem yet to have given such good results as to induce their general adoption.

In the furnaces of steam boilers it is usually considered advisable to allow the gaseous products of combustion to enter the chimney at a temperature of about 600° Fahr. (315° Cent.), or about 2.08 times the absolute temperature of the external air, where natural draught is employed. Rankine has stated that the best temperature of chimney for natural draught is that at which the gases have a density equal to about one half that of the external air. Thus, the temperature of the external air being 60° Fahr. (15°.5 Cent.), its absolute temperature is 521°.2 (261°.75 Cent.), and the required absolute temperature of the gases in the chimney will be this temperature multiplied by $2\frac{1}{2}$, *i.e.*, $521°.2 \times 2\frac{1}{2} = 1085°.8$, and the corresponding temperature on the ordinary scale is 624°.6 Fahr. (339°.2 Cent.).

With forced draught, a considerable economy may be effected by the reduction of the temperature of escaping gases approximately to that of the boiler itself at the point of discharge of the gases.

In heating furnaces, especially in the usual form of reverberating furnaces, the waste of heat is very great, the gaseous products of combustion passing off at exceedingly high temperatures. The total waste amounts in these furnaces to 95 per cent., a ton of coal heating no more than two tons of iron to a welding heat, while its maximum effect should be twenty times that amount in the best cases.

In puddling furnaces, the temperature is necessarily kept at about 3,000° Fahr. (1,649° Cent.), and it is probable that, as a mean, not one fifth of the whole amount of available heat is utilized. In steel melting furnaces a ton of coke should melt twenty-five tons of steel. It actually melts, in average practice, less than a half ton. This waste may be reduced by increasing the temperature of the furnace, but the difficulty experienced in obtaining sufficiently refractory materials of which to construct it, practically places an early limit upon the efficiency secured by that method.

Prideau states that if a furnace where a welding heat is required is maintained at a temperature of nearly 4,000° Fahr. (2,220° Cent.), a four-fold increase of economy is secured by an increase of temperature to the extent of one fourth.

High temperatures secured by methods of which the regenerative furnace affords an illustration, give the most practical and effective means of obtaining economy. Where the combustion of fuel is necessary in the reduction of ores, or in producing other chemical changes, it is not always essential to economy to secure perfect combustion in the furnace. It is in some such cases advisable to estimate the amount of oxygen to be obtained from the ores by the process of deoxidation, and to provide as nearly as possible the quantity of air required to give the additional amount necessary to consume the fuel.

The same care is to be observed in such cases as in the more common one just considered, to obtain exact proportions.

Gruner states that in the wind furnace, which is a most imperfect apparatus, there is utilized, in the fusion of steel, but 1.7 to 3 per cent. of the total calorific power of the fuel. In the reverberatory furnace, melting steel in crucibles, the useful effect is from 2 to 3 per cent. In the Siemens' crucible furnace, 3 to 3.5 per cent. In Siemens' glass furnaces, 5.50 to 6 per cent. In ordinary glass furnaces, 3 per cent. In the fusion of glass upon the open hearth of a reverberatory furnace, 7 per cent.; in the fusion of iron, 8 per cent. In Sie-

mens' and Ponsard furnaces, 15 to 20 per cent. of the total heat is utilized.

The caloric effect is much greater when the fuel is mixed with the material to be melted. In the old cupolas, 29 to 30 per cent.; in the modern cupolas upward of 50 per cent., is realized. Large iron blast furnaces utilize 70 to 80 per cent. of the heat actually generated.

186. Weather Waste.—When coal is exposed to atmospheric influences, a "weather waste" occurs. Oxygen is absorbed, and a slow combustion injures the fuel. Berthelot found, also, that at temperatures not exceeding 530° Fahr. (277° Cent.) hydrogen may be absorbed, and succeeded in converting two thirds of the bituminous coal experimented with into liquid hydrocarbons. Coals freshly mined give out gaseous hydrocarbons, and even anthracite mines, where deep, are not free from danger by the explosion of such gases. The absorption of oxygen, and this loss of hydrogen and carbon, is injurious to the fuel. According to Mursiller, coals containing "fire damp" give it up at or below 626° Fahr. (330° Cent.), and lose their coking property. Coals usually absorb carbonic acid freely.

Richter gives the following as the order of liability to spontaneous combustion:

TABLE XXXVI.

COALS ARRANGED ACCORDING TO DEGREE OF SELF-INFLAMMABILITY.

		IRON PYRITES PER CENT.	WATER PER CENT.	CHARACTER OF THE COAL.
Class I. — Self-inflammable with difficulty	1.	1.13	2.54	Friable.
	2.	1 01 to 3.04	2.75	Very compact.
	3.	1 51	3.90	Very compact.
Class II.—Of medium self-inflammability	4.	1.20	4.50	Firm, schistose, bright.
	5.	1.08	4.55	Hard but brittle.
	6.	1.15	4.75	Moderately friable.
Class III. — Readily self-inflammable	7.	1.12	4.85	Much like No. 1.
	8.	1.00	9.01	Moderately friable, schistose.
	9.	0.83	5.30	Soft, schistose.
	10.	1.35	4.85	Soft, schistose.
	11.	0.84	5.52	Yielded only 2.5 per cent. of ash. Same coal as No. 10, but from a different seam, remarkable for its great self-inflammability.

187. Analyses of Fuel have been frequently and very accurately made.

The following tables give the qualities of samples of each of the more important classes, and are intended to represent average examples of the better varieties of each class.

TABLE XXXVII.

COMPOSITION OF FUEL.—HUNT.

1. Vegetable fibre, or cellulose	C 24	H 20	O 20
2. Wood, mean composition	C 24	H 18.4	O 16.4
3. Peat (Vaux)	C 24	H 14 4	O 10.0
4. " (Regnault)	C 24	H 14.4	O 9.6
5. Brown Coal (Schrötter)	C 24	H 14.3	O 10.6
6. " " (Woskrensky)	C 24	H 13	O 7.6
7. Lignite (Vaux)	C 24	H 11.3	O 6.4
8. Lignite, passing into mineral resin (Regnault)	C 24	H 15	O 3.3
9. Bituminous Coal (Regnault)	C 24	H 10	O 3.3
10. " " "	C 24	H 10	O 1.7
11. " " "	C 24	H 8.4	O 1.2
12. " " "	C 24	H 8.0	O 0.9
13. " " (Kühner and Grüger)	C 24	H 7.4	O 1.3
14. " " mean comp. (Johnson)	C 24	H 9.0	O 2.0 to 4.0
15. Albert Coal (Wetherill)	C 24	H 15.9	O 1.6
16. Asphalt, Auvergne	C 24	H 17.7	O 2.2
17. " Naples	C 24	H 14.6	O 2.0
18. Elastic Bitumen, Derbyshire (Johnson)	C 24	H 22	O 0.3
19. Bitumen of Idria	C 24	H 8	O
20. Petroleum and Naphtha	C 24	H 24	O

TABLE XXXVIII.

COMPOSITION OF VARIOUS FUELS OF THE UNITED STATES.

	C.	*H.*	*O.*	*N.*	*S.*	MOISTURE.	ASH.	SPECIFIC GRAVITY.
Pennsylvania Anthracite.....	78.6	2.5	1.7	0.8	0.4	1.2	14.8	1.45
Rhode Island "	85.8	10.5			3.7			1.85
Massachusetts "	92.0	6.0			2.0			1.78
North Carolina "	83.1	7.8			9.1			
Welsh "	84.2	3.7	2.3	0.9	0.9	1.3	6.7	1.40
Maryland Semi-Bituminous ...	80.5	4.5	2.7	1.1	1.2	1.7	8.3	1.33
Penn'a " " ...	75.8	20.2					4.0	1.32
" " "	59.4	38.8					1.8	1.30
Indiana " " ...	70.0	28.0					2.0	1.24
" " " ...	52.0	39.0					9.0	1.27
Illinois Bituminous	62.6	35.5					1.9	1.30
" (Block) Bituminous ...	58.2	37.1					4.7	
Ill. and Ind. (Cannel) Bt'm'n's.	59.5	36.6					3.9	1.27
Kentucky " "	48.4	48.8					2.8	1.25
Tennessee Bituminous.....	71.0	17.0					12.0	1.45
" "	41.5	56.5					2.5	
Alabama "	54.0	42.6			1.0	1.2	1.2	
Virginia "	55.0	41.0					4.0	
" "	74.0	18.6					7.4	
Cal. and Oregon Lignite.....	50.1	3.9	13.7	0.9	1.5	16.7	13.2	1.32

MONONGAHELA GAS COAL.—CRESSON.

Weight of sample, 60 lbs. (27.27 kilogrammes).

Volatile matter, per cent.....	35.74
Coke " "	64.26
Ash " "	6.66
Yield of gas, cubic feet per pound maximum	5.2
" " " " metres per kilogramme maximum...	0.324
Cubic feet per pound average ..	5.0
" " " " cubic-metres per kilogramme average	0.312
Ton maximum.....	11,648.0
" average.....	11,200.0
Illuminating power, 5 feet per hour = candles	15.0
" " 1 ton coal = lbs. sperm.....	576.0

TABLE XXXIX.

COMPOSITION OF FOREIGN COALS.

	C.	H.	N.	O.	S.	ASH.	SPECIFIC GRAVITY.	AUTHORITY.
Welsh (Anthracite)	90.4	3.3	0.8	3.0	0.9	1.6	1.32	Vaux.
Scotch "	78.5	5.6	1.0	9.7	1.1	4.0	1.26	Muspratt.
English (Newcastle)	82.1	5.3	1.4	5.7	1.2	3.5	1.26	"
" (Lancashire)	77.9	5.3	1.3	9.5	1.4	4.6	1.27	"
" (Derbyshire)	79.7	4.9	1.4	10.3	1.0	2.7	1.29	"
" (Staffordshire)	78.6	5.3	1.8	12.9	0.4	1.0	....	Vaux.
French Anthracite,	94.0	1.4	0.6	....	...	4.0	....	Jacqueline.
" Bituminous	84.0	5.0	1.0	8.0	...	2.0	1.33	Ledieu.
Spanish (Asturias)	53.0			40.0		7.0	....	Johnson.
German (Silesia)	57.9			42.0		2.1	1.26	"
Saxony	80.0			19.0		1.0	1.29	"
Prussia	56.7			18.9		24.4	1.47	"
Hindostan	50.0			35.4		14.6	1.37	"
Brazil	57.9			40.5		1.6	1.29	"
Nova Scotia	60.7			26.8		12.5	1.33	"
Cape Breton	67.6			26.9		5.5	1.34	"
Australia (Lignite)	64.3	4.2	1.0	10.0	0.6	10.0	1.27	Isherwood.
Borneo	70.3	5.4	0.7	19.2	1.2	14.2	1.37	Muspratt.
Chili	70.6	5.8	1.0	13.2	2.0	7.4	1.29	"
Coke	91.5	...	...	....	1.5	7.0	....	"

TABLE XL.

COMPOSITION OF SUNDRY FUELS.

	C.	H.	N.	O.	S.	ASH.	SPECIFIC GRAVITY.	AUTHORITY.
Wood (kiln dried)	50.5	0.1	....	40.7	....	1.6	.....	Watts.
" (air dried)	40.4	4.9	0.9	32.7	....	1.2	0.5 to 1.2	"
Peat (kiln dried)	60.0	6.8	1.3	30.0	....	1.9	.....	Paul.
" (air dried)	46.1	4.6	1.0	23.6	....	1.5	0.5	"
		VOLATILE MATTER.						
Bitumen, United States	24.8			72.4		2.8	.....	Johnson.
" England	52.2			47.5		0.3	.....	"
" France	50.3			41.6		0.1	.....	"
" South America	71.8			26.7		1.5	.....	"
Asphaltum, Syria	24.4			68.0		7.6	.....	"
" "	14.0			72.6		13.6	.....	"
Petroleum, pure U. S.	86.0			14.0		....	0.8	
			REFUSE.					
"Dead Oil"	86.5	7.0		1.5				
Gas, Marsh	75.0	25.0						Watts.
" Olefiant	85.7	14.3						

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TABLE XL.—(*Continued.*)

	CARB. ACID.	CARB. OXIDE.	*H.*	*N.*	HYDRO-CARBON.	AUTHORITY.
Gas from Wood	11.6	34.5	0.7	53.2	....	Ebelmen.
" " Charcoal	0.8	34.1	0.2	64.9	....	"
" " Peat	14.0	22.4	0.5	63.1	....	"
" " Coke	1.3	33.8	0.1	64.8	....	"
" " Lignite	2.0	40.0	42.4	3.2	12.4	
" " Bituminous coal*	4.1	23.7	8.0	61.5	2.2	Siemens.

188. The Heating Effects, or calorific power of good specimens of the various kinds of fuel, is given in the following table, expressed in British thermal units:

TABLE XLI.

CALORIFIC VALUE OF FUELS.

FUEL.	CALORIFIC POWER. RELATIVE.	CALORIFIC POWER. ABSOLUTE.	WATER VAPORIZED AT BOILING POINT, PARTS BY ONE PART.	CUBIC FEET REQUIRED TO STOW ONE TON OF FURNACE COAL.	WEIGHT. POUNDS PER CUBIC FOOT AS STOWED.
Carbon, pure	1.000	14,500	15.00	.....	.....
Hydrogen	4.280	62,500	62.75	.....	.....
Marsh gas	1.816	26,415	26.68	.....	.....
Olefiant gas	1.466	21,328	21.54	.....	.....
Coal, Anthracite	1.020	14,833	14.98	40 to 45	49 to 56
Coal, Bituminous	1.017	14,796	14 95	42 to 48	47 to 53
Coal, Lignite, dry	0.7	10,150	10.35	42	53
Peat, kiln dried	0.7	10,150	10.25	81	25
Peat, air dried	0.526	7,650	7 73	75	30
Wood, kiln dried	0.551	8,029	8.10	.....	.....
Wood, air dried.	0.439	6,385	6.45	56 to 100	22 to 40
Charcoal	0.930	13,500	14.00	.....	.....
Coke	0.940	13,620	14.00	56 to 75	30 to 40
Petroleum, heavy, West Virginia	1.250	18,200	18.75	45	50
Petroleum, light, West Virginia	1.260	18,350	18.90	.....	.....
Petroleum, light, Pennsylvania	1.240	18,050	18.60	.....	.....
Petroleum, heavy, Ohio	1.270	18,450	19.05	.....	.....
Petroleum, Asia	1.240	18,000	18.60	.....	.....
Petroleum, Europe	1.240	18,000	18.60	.....	.....
Shale Oil, France (crude)	1.240	18,000	18.60	.....	.....
Animal fat	0.650	9,000	9.30	.....	.....

* Burned in Siemens' gas producers.

The difference between theoretical and effective heating power for various kinds of fuel is exhibited in the following table, which gives the number of pounds of water evaporated by one pound of fuel, according to European authorities:

TABLE XLII.

FUEL.	HEATING POWER.		
	THEORETICAL.	UNDER STEAM BOILERS.	UNDER OPEN BOILERS.
Petroleum	16.30	10.0 to 14.0	.....
Anthracite	12.45	7 to 11.0	.....
Bituminous Coal	11.51	5.2 to 8.0	5.2
Charcoal	10.77	6.0 to 6.75	3.7
Coke	9 to 10.8	5.0 to 8.0	.....
Lignite	7.7	2.5 to 5.5	1.5 to 2.3
Peat	5.5 to 7.4	2.5 to 5.0	1.7 to 2.3
Wood	4.3 to 5.6	2.5 to 3.75	1.85 to 2.1
Straw	3.0	1.86 to 1.92	.....

TABLE XLIII.

RELATIVE VALUE OF VARIOUS WOODS.—OVERMAN.*

WOOD.	SPECIFIC GRAVITY.	POUNDS IN ONE CORD.	PERCENTAGE CHARCOAL.	SPEC. GRAVITY OF CHARCOAL.	POUNDS OF CHARCOAL IN A BUSHEL.	REL. VALUE OF WOOD.
Hickory, shell bark	1.000	4,469	26.22	0.625	32.89	1.00
Oak, chestnut	0.885	3,955	22.75	0.481	25.31	0.86
" white	0.885	3,821	21.62	0.401	21.10	0.81
Ash, "	0.772	3,450	25.74	0.447	28.78	0.77
Dogwood	0.815	3,643	21.00	0.550	29.94	0.75
Oak, black	0.728	3,254	23.80	0.387	20.36	0.71
" red	0.728	3,254	22.43	0.400	21.05	0.69
Beech, white	0.724	3,236	19.62	0.518	27.26	0.65
Walnut, black	0.681	3,044	22.56	0.418	22 00	0.65
Maple, hard (sugar)	0.644	2,878	21.43	0.431	22.68	0.60
Cedar, red	0.565	2,525	24.72	0.238	12.52	0.56
Magnolia	0.605	2,704	21.59	0.406	21.36	0.56
Maple, soft	0.597	2,668	20.04	0.370	19.47	0.54
Pine, yellow	0.551	2,463	23.73	0.333	17.52	0.54
Sycamore	0.535	2,391	23.60	0.274	19.68	0.52
Butternut	0.567	2,534	20.79	0.237	12.47	0.51
Pine, New Jersey	0.478	2,137	24.88	0.385	20.26	0.48
" pitch	0.426	1,904	26.76	0.298	15.68	0.43
" white	0.418	1,868	24.35	0.293	15.42	0.42
Poplar, Lombardy	0.397	1,774	25.00	0.245	12.85	0.40
Chestnut	0.552	2,333	25.29	0.379	19.74	0.52
Poplar, yellow	0.563	2,516	21.81	0.383	20.15	0.52

* *Metallurgy.* N. Y., D. Appleton & Co., 1864.

ORDINARY CALORIFIC VALUES AS COMPARED WITH GOOD BITUMINOUS COAL.

	Lbs. Coal.
1 cord (3.62 cubic metres) of seasoned hickory or hard maple ...	2,000
1 " " " " " white oak.....	1,750
1 " " " " " beech, red or black oak...	1,500
1 " " " " " poplar, chestnut, or elm...	1,000
1 " " " " " soft pine.....	960

189. Analyses of Ash.—The following analyses represent the character of ashes of anthracite and bituminous coals.

They may be taken as examples, simply, since the ash of coal intended for metallurgical purposes should invariably be examined before taking the fuel for any important work.

ANALYSES OF ASH.

	SPECIFIC GRAVITY.	COLOR OF ASH.	SILICA.	ALUMINA.	OXIDE IRON.	LIME.	MAGNESIA	LOSS.	ACIDS, S. AND P.
Pennsylvania Anthracite....	1.559	Reddish Buff.	45.6	42.75	9.43	1.41	0.33	0.48	....
" Bituminous...	1.372	Gray	76.0	21.00	2.60	...	....	0.40	....
Welsh Anthracite.....	1.32	.....	40.0	44.8	....	12.0	trace	....	2.97
Scotch Bituminous.....	1.26	.....	37.6	52.0	....	3.7	1.1	....	5.02
Lignite.....	1.27	.....	19.3	11.6	5.8	23.7	2.6	....	33.8

Where the difference between two coals lies principally in their relative percentages of ash, the comparison is made in the manner about to be described.

The anthracites contain so little other combustible matter that, as shown by Professor Johnson,* their calorific value is proportional very nearly to the percentage of contained carbon.

190. The Commercial Value of Fuels is somewhat modified by the depreciation produced by presence of non-combustible matter; this modification occurs in the following ways:

* Report to the Navy Department on American Coals.

(1.) A certain amount of carbon is required to heat the whole mass to the temperature of the furnace. Of this a large part is lost. It follows, therefore, that a coal containing a certain small quantity of combustible would have no calorific value, and, consequently, would be worthless in the market.

(2.) The presence of a high percentage of ash in a fuel checks combustion by its mechanical mixture with the combustible portion of the coal. A coal will, hence, have no commercial value when the proportion of refuse reaches a limit at which combustion becomes impossible in consequence of this action.

(3.) The cost of transportation of ash being as great as that of transporting the combustible, the consumer paying for ash at the same rate as for the carbon, and also being compelled to go to additional expense for the removal of ash; these facts also determine a limit beyond which an increased proportion of ash renders the fuel valueless.

(4.) The determination of the financial losses due to increased wear and tear of furnaces and boilers, of incidental losses due to inequality or insufficiency of heat-supply, and to the many other direct and indirect charges to be made against a poor fuel, also indicate a limit which has a different value for each case, but which, in most cases, is difficult of even approximate determination. The determination of the minimum proportion of combustible, under the first case, is made as follows, assuming this heat to be entirely wasted:

(*a.*) The specific heat of ash is usually nearly 0.20. Let X represent the percentage of ash which is sufficient to render the coal valueless. Then, since each pound of carbon has a heating power of 14,500 British thermal units (3,625 calories), $14{,}500\ (100 - X) = A$, represents the available heat of a unit in weight of the fuel; $100 \times 0.20 \times 3{,}000^\circ = B$, represents the heat required to raise this same amount of coal to a temperature equal to that of the furnace, which is here assumed at 3,000° Fahr. (1,633° Cent.) above the surrounding atmosphere.

Since these quantities A and B are equal: $14{,}500\,(100 - X) = 100 \times 0.2 \times 3{,}000°$, and $X = 96$ per cent.

The minimum quantity of fuel permissible is, therefore, four per cent., where the first consideration only is taken into the account.

(*b.*) The influence of the second condition is at present not determinable in the absence of experiment.

(*c.*) The cost of transportation of ash to the consumer, as a part of the fuel, is not taken in the determination of its value to him. The removal of ash is a tax upon the consumer which may be considered as the equivalent of the loss of a certain weight of combustible received. Since this cost fluctuates with the market value of coal, and since its amount is determined by the same causes, it is easy to make the statement in that form. This cost is about ten per cent. of the value of coal, weight for weight, and is therefore assumed at ten per cent. of the proportion of ash found in the coal.

(*d.*) The losses, direct and indirect, coming under the fourth head, vary greatly, and are sometimes very serious. An approximate estimate for an average example is taken, and is considered to be equal, at least, to a percentage of the total value of coal, in utilizable carbon, which equals one-half the percentage of ash. Comparing two anthracites, which we will suppose to contain, respectively, fifteen and twenty-five per cent. ash, eighty-five and seventy-five per cent. carbon, the first being a well known standard coal, selling in the market at six dollars per ton (1,016 kilogrammes), we may, using this system of charging losses against equivalent values in combustible carbon, determine the proper commercial value of the second kind.

First Example.—From the 85 per cent. carbon:

Deduct for heating to furnace temperature.....	0.040
" " transportation of refuse 10 per cent. of 15.....	0.015
" " other losses 50 per cent. of 15.....	0.075
Total.....	0.130

leaving valuable and available carbon 85 — 13 = 72 per cent.

Second Example.—From the 75 per cent. carbon:

Deduct for heating to furnace temperature.....	0.040
" " removal of ash 10 per cent. of 25.....	0.025
" " sundry losses 50 per cent. of 25.....	0.125
Total.....	0.190

leaving valuable available carbon $75 - 19 = 56$ per cent.

Finally, if \$6.00 is paid for 72 per cent. available combustible, for 56 per cent. we should pay $\frac{56 \times 6}{72} = \$4.66\frac{2}{3}$.

Third Example.—Taking a third example, in which the fuel contains the exceptionally large proportion of 30 per cent. ash, we should, by similar method, proceed as follows, deducting from the seventy per cent. carbon as before the estimated charges against it.

Deduct for heating.....	0.040
" " removal of ash 10 per cent. of 30.....	0.030
" " sundry expenses 50 per cent. of 30.....	0.150
Total.....	0.220

leaving available carbon, $70 - 22 = 48$ per cent. which would be worth $\frac{48 \times 6}{72} = \$4.00$.

Had the first coal had a market value of seven dollars per ton, the second and third would have been worth, respectively, \$5.44½ and \$4.66⅔.

Expressing this operation by symbols, if V represents the value of the fuel in percentage of pure carbon, and A equal the percentage of ash, $V = 0.96 - 1.60A$.

This method is evidently largely empirical, and its results are but approximate. It is however simple and easily applied, and will often be found of use in the absence of more precise means of determination.

191. Products of Distillation.—The following is given as the constitution of an average quality of bituminous coal, and of pine wood as determined by fractional distillation.

COMPOSITION OF BITUMINOUS COAL.

Nitrogen	0.035
Ammonia	0.211
Hydrogen	0.499
Sulph. hydrogen	0.549
Olefiant gas	0.753
Carbonic oxide	1.035
Carbonic acid	1.073
Light carb. hydrogen	7.021
Water	7.569
Tar	12.230
Coke	68.925

PRODUCTS OF DISTILLATION OF PITCH PINE, 1,000 LBS. (454 KILOGRAMMES.)

Illuminating gas	400 cub. ft.	1138	litres.
Charcoal	260 lbs.	118	kilog.
Tar	460 "	209	"
Pitch	120 "	54.5	"
Pyroligneous acid	320 "	145.5	"
Spirits of turpentine	60 "	27.2	"

CHAPTER V.

LUBRICANTS.*

192. Friction is a resistance which is always met when two bodies or particles, whether solid, liquid, or gaseous, are compelled to move, one upon another. There are three kinds of friction, so called: rolling, and sliding with solids, and fluid friction with liquids and gases. These are all governed by different laws, and with each the statements of those laws, as usually given by authorities, probably require some modification.

193. Journal Friction.—In all ordinary cases, as of journals in well-lubricated bearings, the friction probably combines both the sliding of solids and fluid friction, and, consequently, the laws of friction, as determined by experiment upon journals and as affecting journals are quite different from the laws of friction of solids which, only, are almost universally enunciated in hand-books.

In fact, as will be presently seen, the resistance of journals revolving in their bearings not only follows a law which is widely different from that given in earlier works, but, at usual speeds and pressures, the amount of that resistance may be found to differ immensely from that indicated in engineering and mechanical hand-books which have hitherto appeared.

Combining, as is probable, both forms of frictional resistance, it would therefore seem evident that the laws of friction of journals include both methods of variation of resistance, and reconcile wide variations of the facts ascertained by experiment from those predicted by the commonly asserted, but as here applied erroneous, so-called laws of friction.

194. Fluid Friction is found to vary with the square of

* Abridged from Treatise on Friction and Lubrication; R. H. Thurston, N. Y., 1875.

the velocity, and is proportional to the area of rubbing surface, and is probably independent of the pressure. In hundreds of experiments, with pressures varying from 5 to 2,000 pounds to the square inch, the writer has found the friction of well lubricated journals to vary in such a manner as to prove that the law which governs such cases is quite different from that which applies with dry solids, and has thus found the deduction above given confirmed. When a lubricant is interposed between the rubbing surfaces of a revolving journal and its bearing, or between a sliding plane surface and its support, if acting effectively, it forms a fluid cushion separating the surfaces more or less perfectly as it is more or less viscous, and as capillarity is greater or less, thus giving the resistance to motion more or less of the character of fluid friction. Thus the same surfaces lubricated with the same material may, under light pressure, exhibit a resistance varying approximately according to the law of fluid resistance, and under comparatively heavy loads, it may be governed more nearly by the laws of friction of solids, under intermediate pressures its behavior being of intermediate character.

195. **The Coefficient of Sliding Friction** as ordinarily stated, or *the ratio of frictional resistance to the total pressure* holding two sliding solids in contact, which is the usual measure of friction, varies directly as some function of the pressure, and is nearly independent of the velocity of motion and of the area of the surfaces in contact.

The "friction of quiescence," or the resistance to starting the two bodies into relative motion, is greater than the "friction of motion;" but it is subject to the same laws. The law just stated is subject to limitation. It becomes untrue when the pressure is so great as to produce a depression in, or to abrade the rubbing surfaces.

The friction becomes greater than is indicated by the stated law when the pressure becomes so low, also, that the resistance is principally due to the viscosity of the interposed liquid; and it then follows an entirely new law. Between these limits the resistance due to friction between solid *lubricated* surfaces is of a mixed nature.

There are two usual ways of measuring friction, and of determining the coefficients for solids, which are described in text-books:

(1.) Place the two bodies in such a position that the rubbing surface shall be horizontal; load the upper one to the proposed extent and then apply a measureable force to produce motion, either by means of a weight or a spring balance. The weight of the uppermost piece with its load makes up the quantity W, and the applied force is F. The "coefficient" of friction is the ratio of these quantities, and we have $f = \frac{F}{W}$. This value f may be less than one per cent., or it may be over fifty per cent., according to the nature of the materials and their condition as respects lubrication.

(2.) The other method is equally easy of application. Lay the one solid on the other and tilt them up until the upper will slide on the lower. The tangent of the angle is the coefficient of friction, and we simply measure the height of a point in the surface on which sliding occurs, and the horizontal distance of the vertical from a point in the same surface which lies on a level with that to which this height was measured, and the division of the former by the latter measurement gives the value of the coefficient of friction.

Under ordinary conditions, the engineer or the physicist calculates the resistance due to sliding friction as he does that of rolling friction, by multiplying the total sliding weight by a "coefficient" or factor, the value of which has been determined for certain general cases, by experiment.

In illustration of the use of the coefficient of friction, it need only be said that the multiplication of the measure of load on pressure in any case by the coefficient, gives the measure of the force resisting sliding; the division of the measure of the latter, when known, by the coefficient, gives the measure of the magnitude of the pressure or the load.

That the tangent of the inclination of a plane on which a body free to move will just start into motion, and that the tangent of the angle at which sliding occurs at a uniform ve-

locity, measure respectively the values of the coefficients for rest and for motion, is thus shown:

Let α = the angle.
W = the weight carried.
R = the normal pressure between the two surfaces.
f = the value of the coefficient.

Then the resistance of friction measured parallel with the surface of the inclined plane will be fR, and we shall have:

$$fR - W \sin \alpha = 0,$$
$$R - W \cos \alpha = 0.$$

Whence:

$$f \cos \alpha - \sin \alpha = 0, \text{ and } f = \tan \alpha. \quad . \quad . \quad (1).$$

The two following propositions will illustrate the mathematical application of the principles of friction:

(1.) To determine the limiting ratios of P to W, friction acting up or down the plane, when P represents the effort exerted on the sliding body, W is its weight, and R is the reaction of the plane.

Since there exists an equilibrium of forces, where W acts vertically downward, R acts perpendicularly to the surface of the inclined plane, and P acts in any given direction, making an angle β with the surface of the plane, we shall have for the maximum:

$$P \cos \beta - fR - W \sin \alpha = 0,$$
$$P \sin \beta + R - W \cos \alpha = 0.$$

Whence:

$$P = \frac{W(\sin \alpha + f \cos \alpha)}{\cos \beta + f \sin \beta}. \quad . \quad . \quad . \quad . \quad (2.)$$

(2.) For a minimum value, we get:

$$P \cos \beta + fR - W \sin \alpha = 0,$$
$$P \sin \beta + R - W \cos \alpha = 0.$$

And

$$P = \frac{W(\sin \alpha - f \cos \alpha)}{\cos \beta - f \sin \beta}. \quad . \quad . \quad . \quad . \quad (3).$$

196. Experiments in this important field were first made by Amontons, who published, in 1699, in the memoirs of the old Academy of Sciences, values which gave a coefficient of about 0.33, or one-third, when the rubbing surfaces are coated with lard, a value which is far too high for ordinary work. Coulomb, a French officer of engineers, and a member of the Institute, reported experiments* in 1781, which were more complete and more accurate, and in which he determined both the friction of rest and that of motion. He states that the friction is proportional to the pressure, and independent of the extent of surface and of the velocity of rubbing, and proves that the friction of rest is greater than that of motion.

The most complete series of experiments ever made were, however, those of General Morin. Although made from 1831 to 1834, they are still quoted as standard, by nearly all text-books and works on engineering.† The apparatus consisted of a box, which could be loaded at pleasure, sliding on a bed and moved by a weighted cord passing over a pulley at the end of bed. The pull was measured and registered by a recording dynamometer, attaching the cord to the box, which furnished graphic representations of all the variations of frictional resistance. The curves thus described were parabolas, proving, for the small pressures and for the speeds adopted, that the friction was constant and independent of the velocity. It was found proportional to the pressure and independent also of the area of surfaces. The same law, as respects pressure and area of surface, held in the determinations of the friction of rest.

The slightest jar was found often sufficient to reduce the friction of rest to that of motion. Fatty unguents were found to diminish the amount of friction without changing the law; water proved to have no value as a lubricant. Friction during shock was, so far as could be determined, subject to the same laws. The pressures adopted in these experiments were usually low, and therefore gave exceedingly high values of the coefficient of friction—values which are rarely attained in engineering practice.

* *Vide* "Recueil des Savants Etrangers," Vols. IV and V.

† "Morin's Mechanics;" p. 261, D. Appleton & Co., New York, 1860.

197. The "Angle of Friction," the "angle of repose," or the "limiting angle of friction," as it is variously termed, is that angle of which the tangent is the coefficient of friction. It measures the inclination from the horizontal at which the sliding body would just start on a smooth plane, or would just retain motion once acquired, according as the coefficient is that of rest or of motion.

198. Coefficient of Friction.—The following table gives the value of the coefficients as given hitherto by standard authorities, usually by Morin:

TABLE XLIV.

COEFFICIENTS OF FRICTION.

MATERIAL.	CONDITION OF SURFACES.	*f*.	FRICTION ANGLE.
Brick on limestone	Dry	0.67	33° 50′
Cast iron on cast iron	Slightly greased	0.16	9° 6′
" on oak	Wet	0.65	33° 2′
Copper on oak		0.17	9° 38
" "	Greased	0.11	6° 17′
Leather on cast iron		0.28	15° 39′
" "	Wet	0.38	20° 49
" "	Oiled	0.12	6° 51′
Leather on oak	Fibres parallel	0.74	36° 30′
" "	" crossed	0.47	25° 11′
Oak on oak	Fibres parallel, dry	0.62	31° 48′
"	" crossed, dry	0.54	28° 22′
"	" parallel, soaped	0.44	23° 45′
"	" crossed, wet	0.71	35° 23′
"	" end to side, dry	0.43	23° 16′
"	" parallel, greased	0.07	4° 6′
"	Heavily loaded and greased	0.15	8° 45′
Oak on pine	Fibres parallel	0.67	33° 50′
" limestone	" on end	0.63	32° 15′
" hempen cord	" parallel	0.80	38° 40′
Pine on pine	" "	0.56	29° 15′
" oak	" "	0.53	27° 56′
Smooth granite on rough granite		0.66	33° 26′
Stone on dry clay		0.51	27° 2′
" wet clay		0.34	18° 47′
Wrought iron on oak		0.62	31° 48′
" " "	Wet	0.65	33° 2′
" " on wrought iron		0.28	15° 39
" " on cast iron		0.19	10° 46′
" " on limestone		0.49	26° 7′
Wood on metal	Greased	0.10	6° 0
Wood on smooth stone	Dry	0.58	30° 7′
" " earth	"	0.33	18° 16′

199. The Friction of Pump-pistons has been determined by d'Aubuisson, and found to be directly proportional to the diameter of the pump and to the pressure.

The friction of hydraulic-press plungers has been found by Hicks to be very nearly, when well designed and in good order, twenty per cent. divided by their diameter in inches; a four-inch plunger offering a resistance of five per cent., and a twenty-inch press one per cent. of the total load.

200. The Friction of Journals has been studied by Rennie and by Morin, and recently by many engineers. The following are the figures given by Morin.

TABLE XLV.

FRICTION OF JOURNALS IN MOTION.—MORIN.

MATERIALS.	LUBRICANTS.	COEFFICIENT OF FRICTION. LUBRICATION.	
		INTERMITTENT.	CONTINUOUS.
Cast iron on cast iron....	Oil, lard, tallow..	0.07 to 0.08	0.03 to 0.04
	" and water...	0.08	
	Asphalte.....	0.054	
	Unctuous.....	0.14	
	" and wet..	0.14	
Cast iron on bronze.....	Oil, lard, tallow ..	0.07 to 0.08	0.03 to 0.054
	Unctuous.....	0.16	
	" and wet...	0.16	
	" (slightly)..	0.19	*
	Dry.....	0.18	
Cast iron on lignum-vitæ.	Oil, lard.....	....	0.090†
	Unctu's (oil or lard)	0.10	
	" lard and graphite.....	0.14	
Wrought iron on cast iron	Oil, lard, tallow...	0.07 to 0.08	0.030 to 0.054
Wrought iron on bronze..	Oil, tallow, lard...	0.07 to 0.08	0.030 to 0.054
	Unctuous and wet.	0.19	
	" (slightly)..	0.25	‡
Iron on lignum-vitæ	Oil, lard.....	0.11	
	Unctuous.....	0.19	
Bronze on bronze.....	Olive oil.....	0.10	
	Lard	0.09	
Bronze on cast iron.....	Oil, tallow.....	....	0.030 to 0.054
Lignum-vitæ on cast iron.	Lard	0.12	
	Unctuous.....	0.15	
Lignum-vitæ on lignum-vitæ.....	Lard	....	0.07

* Wear began. † Wood slightly greasy. ‡ Wear commenced.

They are to be compared with those to be presently given as derived from later experiments, and may be taken as representing maximum values for new journals and comparatively small loads. The journals were from two to four inches in diameter, and loaded with from 330 pounds to 2 tons.

As early as 1831, Nicholas Wood determined the coefficient of friction on old well-worn axles, under conditions not fully specified, to be about 0.02. Later German experiments, with pressures of 200 to 250 pounds per square inch, gave, at 230 revolutions, $f = 0.00891$ to $f = 0.013$, and it was concluded that these values could be reduced. Still later experiments showed an increased resistance in higher ratio than an increase of load, and an increase with increase of velocity, while experiments at Hanover led to the conclusions that, under loads of from 320 to 1,250 pounds on the journal, the coefficient for iron axles lubricated with rape-seed oil and running in white metal bearings is 0.009 to 0.0009; that with gun-bronze bearings the figures became 0.014; that the value is independent of the weight of load within usual limits; that the area of the journal does not affect the resistance; that resistance is independent of the velocity of rubbing; that grease gives a higher figure than oil for light loads, but the same under heavy loads.*

201. The Frictional Resistance of Mill-shafting has been determined by the very numerous and extended experiments of Mr. Samuel Webber. The pressures are here not very high, and Webber's values for the coefficient of friction average very nearly the same as the figures obtained by Morin. They are, for intermittent lubrication, 0.066, and for continuous oiling, 0.044. Morin obtained 0.075 and 0.042.

Clark obtains formulas for the work of friction for one revolution and the horse-power absorbed by shafting, using $f = 0.070$ and $f = 0.043$.

$$\text{Work} = U = 0.0182\ Wd, \text{ for ordinary oiling.} \quad (4).$$
$$\text{Work} = U = 0.0112\ Wd, \text{ for continuous oiling.} \quad (5).$$

*W. R. Browne, *Railroad Gazette*, August 16, 1878.

$$HP = \frac{0.0182\ WdR}{33{,}000} = \frac{WdR}{1{,}800{,}000} \text{ for ordinary oiling, . . (6).}$$

$$= \frac{0.0112\ WdR}{33{,}000} = \frac{WdR}{2{,}950{,}000} \text{ for continuous oiling, . . (7).}$$

in which W = the total load, d = diameter of journals, R = revolutions per minute.*

The coefficient determined by Webber varies from 0.033 to 0.055, or from one-thirtieth to one-twentieth, with continuous lubrication, and from 0.052 to 0.114, or from one-twentieth to one-ninth for ordinary lubrication.

202. Lubricants.—From what has been stated it is seen that the amount of frictional resistance to the motion of machinery is determined by the character of the lubricating material. It thus happens that all recent experiments in this field have been made in investigations of the value of lubricants, which investigations include very much more than a single measure of the coefficient of friction; and the later determination of the friction of lubricated surfaces at the various pressures and speeds which are commonly met with in modern machinery will therefore be given after discussing the nature of lubricating materials and the standard or other methods of ascertaining their value. The tables to be hereafter given will serve the mechanic, the engineer, or the designer of machinery as data by means of which to estimate the probable losses of power by friction, under almost every set of conditions met with in practice.

The value of a lubricant *as* a lubricant is entirely independent of the market price except so far as the demand of consumers of unguents affects the market. Some of these materials which would be most useful in reducing friction, could they be so applied, are entirely unknown to consumers of lubricating substances because of their monopoly for other purposes, for which they are in such demand as to entirely remove them from a market in which other unguents can be obtained at such comparatively low price as to throw the

* "Manual," p. 763.

former quite out of competition in the oil market. The best known lubricant for general purposes—sperm oil—is far less used than the less excellent but cheaper lard oil, which, in turn, is less generally used than the mineral and mixed oils with which the market is always largely supplied.

The effect of friction—rolling as well as sliding—is to wear and abrade solids, and, with fluids as well as with solids, to generate heat to an amount which is the exact equivalent of the work of friction, and which, could it be all collected and measured, would be found to be a precise measure of the power wasted and lost in consequence of the friction. The amount of heat thus produced is equal to one British "thermal unit" * for each 772 foot-pounds of work expended in overcoming friction. This figure is that known as Joule's "mechanical equivalent of heat." Where the work is measured by the metric system, this corresponds to the development of one "*calorie*" † of heat for each 424 kilogrammetres of work done in overcoming frictional resistance.

This evolution of heat has a serious ill effect in several ways: it reduces the viscosity of lubricants, thus rendering them more liable to exude from between the rubbing surfaces at high pressures; it is cumulative, and causes danger to become more and more imminent as it progresses beyond the limit within which conduction and radiation may dispose of it to surrounding objects as fast as generated; it causes serious injury to the surfaces in contact, cracking, distorting, and abrading them, and thus increasing the friction while destroying journals and bearings; it often even ignites the lubricant, overheating, softening, and weakening the abrading metals, and endangering all combustible material in its neighborhood. The journals of machinery are often actually welded into their bearings. The burning of mills and of steam vessels, and the breakage of car axles, and consequent destruction of trains loaded with passengers, sometimes result from the use

* A British thermal unit is the quantity of heat required to raise the temperature of a pound of water, from 39°.1 to 40°.1 Fahrenheit.

† The metric "*calorie*" is the heat required to raise the temperature of a kilogramme of water, from 3°.9 to 4°.9 Centigrade.

of improper lubricants or of badly proportioned rubbing parts.

203. Lubrication has for its objects, therefore, both the reduction of friction and the prevention of excessive development of heat, and the engineer resorts to the expedient of interposing between the rubbing surfaces a substance having the lowest possible coefficient of friction and the greatest capacity for preventing or reducing the development of heat. It is evident that in order that any substance may be efficient as a lubricating material, it must possess the following characteristics:

(1.) Enough "body," or combined capillarity and viscosity, to keep the surfaces between which it is interposed from coming in contact under maximum pressure.

(2.) The greatest fluidity consistent with the preceding requirements, *i. e.*, the least fluid-friction allowable.

(3.) The lowest possible coefficient of friction under the conditions of actual use, *i. e.*, the sum of the two components, solid and fluid friction, should be a minimum.

(4.) A maximum capacity for receiving, transmitting, storing, and carrying away heat.

(5.) Freedom from tendency to decompose or to change in composition by gumming or otherwise, on exposure to the air or while in use.

(6.) Entire absence of acid or other properties liable to produce injury of materials or metals with which they may be brought in contact.

(7.) A high temperature of vaporization and of decomposition, and a low temperature of solidification.

(8.) Special adaptation to the conditions as to speed and pressure of rubbing surfaces under which the unguent is to be used.

(9.) It must be free from grit and from all foreign matter.

204. The Value of a Lubricant to the consumer, as is seen from what has been just stated, depends on its cost in the market, its efficiency in reducing friction, its durability under wear, its freedom from liability to "gum," its freedom from

acid and from grit, and its permanence of composition and of physical condition when subjected to changes of temperature, and also, frequently, its capacity for carrying away heat from journals already heated.

Thus, sperm oil is known by all experienced mechanics and by all dealers in oil to be one of the very best of known lubricants; but its high price precludes its use, except for special purposes. Some other oils are cheap, but have little lubricating power; still others are good reducers of friction, but do not wear well, or frequently cannot be retained on the journals; others, as linseed and the drying oils generally, although sometimes excellent otherwise, gum so seriously that they cannot be used for lubrication; while a good deal of the tallow in the market, and some other lubricants, contain acids of decomposition, or acids which have been used in their clarification, which have not been so completely removed as to prevent injury by their action on the metals. Some lubricants cannot be used at low temperatures because they are liable to congeal, and others cannot be used in steam cylinders or where high temperature is liable to be met with, because they decompose or vaporize under such circumstances.

Every dealer in oils and every consumer of lubricants who desires to know with certainty whether he has, in any case, precisely that lubricant and that quality which is nominally given him, must resort to some method of identification of the material. Every user of such a material who desires to know whether it is well adapted to a specific purpose, or who wishes to find out what are its peculiar characteristics, must find some method of testing it, and of thus ascertaining whether, under the conditions arising in his practice, it will serve his purpose. He must know whether it will bear the pressure, and will run without heating his journal, at the speed to which he must subject it.

Many different conditions must therefore be studied, and the behavior of the lubricant determined with reference to each before it can be known, with any degree of certainty, what is its real value for any specified purpose, and it is

equally evident that the conditions under which the behavior of an oil or other lubricating material is to be determined, should always be those approximating with the greatest possible exactness to the conditions proposed in its actual use.

205. In form, lubricants are sometimes solid, but usually liquid, and of the liquid unguents there are many varieties in the market which differ in their viscosity and cohesiveness as widely as they do in nearly every other quality, and range from the most liquid and water-like watch-oils to those "heavy-bodied" and densest of all the oils—castor oil and rosin oil. We have semi-solid lubricants, of which tallow, soap, and wax are illustrations, and still others are perfectly hard and solid, as graphite and soapstone.

The engineer also uses what are known as "anti-friction metals," one of the oldest and best known of which is the so-called "Babbitt-metal." These are permanently fixed in the bearings in the form of linings, and their peculiar use is to present to the journal, instead of the hard, unyielding, and resistant surface of the metal itself, a material which more readily and perfectly adapts itself to the form of the journal which it supports. Lead has been introduced by Mr. Hopkins to act thus temporarily; gradually, as it wears, letting the journal down to a good bearing on the brass of the boxes.

Metalline and some other anti-friction metals are used without lubricants, and are, therefore, themselves, as truly lubricants as are plumbago and similar solid materials which are usually finely ground and interposed between rubbing surfaces.

In some cases no lubricant will suffice to keep a journal from heating and even "cutting;" in such an event the "brasses" are sometimes made hollow and a stream of water is made to circulate through them, thus effectually keeping them cool.

In the "*Palier glissant*" of Girard, and the "Water-bearings" of Shaw, the journal is supported upon a cushion of water which is forced into a space in the journal beneath it by a pump, and at such a pressure that the journal is perfectly "water-borne" and revolves on the liquid cushion.

Shaw has applied this plan successfully in supporting vertical shafts.

The most generally applied fluid lubricants are the better known and cheaper kinds of animal, fish, vegetable, and mineral oils; of these, sperm stands admittedly at the head of the list; lard, neats'-foot, whale,* tallow, seal, and horse oils are all largely used, either alone or mixed. The vegetable oils in use are olive, which is by far most generally used in some countries, and cotton-seed oil in the United States. Palm, rape-seed, oleine, colza, poppy, peanut, rosin, cocoanut, and castor oils† are all more or less employed in lubrication. Of the fish oils, porpoise, cod, and menhaden oils are most used. The mineral oils are of two general classes: the shale oils, obtained from certain shales, and the petroleums, which come from extensive oil lakes, situated usually far beneath the surface of the earth, and which are principally obtained from oil wells in Pennsylvania and other of the United States.

Of these oils, sperm is still largely used, notwithstanding its high price, since it excels nearly all others in its power of reducing friction, and immensely excels them in endurance. Rape-seed is, in some districts, now displacing olive oil as a lubricant; but the mineral oils, pure or mixed, are rapidly taking the leading place in all markets.

206. The Petroleums are found in China, India, Italy, and other parts of the world. The island of Trinidad contains a lake of petroleum—"Pitch Lake"—the shores of which are composed of bitumen, produced by its evaporation and oxidation. But the greater part of the petroleum of the world is produced in Pennsylvania, West Virginia, and Ohio. According to Spon,

(1.) A mineral oil flashing below 300° Fahr. (150° Cent.), is unsafe.

(2.) A mineral oil losing more than 5 per cent. in ten hours at 60° to 70° Fahr. (15° to 20° Cent.), is inadmissible, as the evaporation creates a gum, or leaves the bearing dry.

* The whale is not a fish, but an animal classed among the mammals.

† Linseed oil is a good reducer of friction, but dries and "gums" too rapidly to permit its use as a lubricant.

(3.) The most fluid oil that will remain in its place, fulfilling other conditions, is the best for all light bearings at high speeds.

(4.) The best oil is that which has the greatest adhesion to metallic surfaces, and the least cohesion in its own particles; in this respect fine mineral oils stand 1st, sperm oil 2d, neats'-foot oil 3d, and lard oil 4th; consequently the finest mineral oils are best for light bearings and high velocities; the best animal oil to give body to fine mineral oils is sperm oil; lard and neats'-foot oils may replace sperm oil when greater tenacity is required.

(5.) The best mineral oil for steam cylinders is one having a density of 0.893, and a flashing point of 680° Fahr. (360° Cent.).

(6.) The best mineral oil for heavy machinery has a density of 0.880, and a flashing point of 520° Fahr. (269° Cent.).

(7.) The best mineral oil for light bearings and high velocities has a density of 0.871, and a flashing point of 500° Fahr. (262° Cent.).

(8.) Mineral oils alone are not suited for very heavy machinery, on account of their want of body, but well purified animal oils are applicable to the heaviest machinery.

(9.) Olive oil stands first among vegetable oils, as it can be purified without the aid of mineral acids. The other vegetable oils, which, though far inferior to olive oil, are admissible as lubricants, are, in their order of merit, sesamé, earth-nut, rape and colza, and cotton-seed oils.

(10.) No oil is admissible which has been purified by means of mineral acids.

Pure natural West Virginia oil, 29° gravity Baumé, is suitable for all kinds of heavy machinery, and will remain limpid in the coldest climates. It is preferred by many consumers to sperm or lard oils.

Oil of heavy body, and a fire test of from 330° to 350° Fahr. (165°.5 to 177° Cent.), is often used for railroad car axles, heavy machinery, locomotives, or for any purpose where great heat is to be provided against, and for bearings where heavy weight is sustained. It has excellent wearing properties,

and will lubricate and keep car journals and heavy bearings cool when oils of a lower fire-test would volatilize. It can be used during all seasons of the year. Properly refined, it is entirely free from sand, tar, and still-bottom impurities. For factory use, high speed, with both heavy and light bearings, and wherever the lubricator is fed to bearings by capillary attraction, it is a good lubricant.

All vegetable and animal oils are compounds of glycerine, with fatty acids. When they become old, decomposition takes place and acid is set free, by which action, as is commonly said, the oils become rancid. This rancid oil, or acid, will attack and injure the machinery. Again, all animal oils contain more or less gummy matter, which accumulates when exposed to the action of the atmosphere, and will consequently retard the motion of the machinery.

Mineral oil does not absorb oxygen, whether alone or in contact with cotton wool, and cannot therefore take fire spontaneously, as animal and vegetable oils do.

The consumption of petroleums, or mineral lubricating oils, is largely increasing; they are used on all kinds of machinery; they are the safest and cheapest lubricators, and superior to animal and vegetable oils and greases; they are safer, on account of their non-oxidizing properties and their high fire test, and the heat they will resist before vaporizing; they are cheaper in price, and more economical, saving both machinery and fuel; they are more reliable, because they are entirely pure and always uniform in quality; they last longer and work cleaner; they are perfectly free from acids and every impurity; they neither gum, stain machinery nor the manufacturers' products.

207. The Greases, or semi-fluid lubricants, are sometimes used in their natural state, as tallow, lard, and other similar substances, and sometimes are made up artificially, *e. g.*, the various kinds of soap. Mixtures of tallow and black-lead, white-lead and oil, and other mixtures containing sulphur, are often used.

For some special purposes, certain mixtures are used, as, for cooling hot journals, mixtures of oil and of white or black

lead, oil and sulphur, or greases composed of oil to which some alkaline water has been added. The author has, with very large and troublesome marine engines, found sulphur and oil on the journal, with the application—very cautiously—of cold water externally, to work best.

For a railroad grease, a mixture of equal parts of tallow and palm oil, with water to which one-eighth of its weight of caustic soda has been added, is a good one, mixing them quite warm. Two parts paraffine, one of lard and three of lime-water is said to be a good grease, especially for heavy, slow-moving journals.

A mixture of eight parts of bayberry wax with one of graphite is very good, also.

Grease is usually employed in lubricating axle-journals in Great Britain, and is generally of palm oil. The following are said to be good compositions* for that climate:

RAILROAD AXLE GREASE.

	For Summer.	For Winter.
Tallow	504 parts.	420 parts.
Palm Oil	280 "	280 "
Sperm Oil	22 "	35 "
Caustic Soda	120 "	126 "
Water	1,370 "	1,524 "

On German railroads the following composition is used:

	Parts.
Tallow	24.60
Palm Oil	9.80
Rape-seed Oil	1.10
Soda	5.20
Water	59.30
	100.00

The following is Austrian:

	Tallow.	Olive Oil.	Old Grease.
For Winter	100	20	13
For Spring and Autumn	100	10	10
For Summer	100	1	10

* W. R. Browne, *Railroad Gazette*, Aug. 9, 1875.

208. The Solid Lubricants are often found to work well when no fluid will answer at all. Some of them sustain immense pressures without injury. Those in general use are certain metallic compositions, mixtures of metallic with non-metallic elements—graphite, sulphur, soapstone, asbestos, lampblack, and white lead (carbonate of lead). In some cases they are permanently and solidly fixed, as already stated, and sometimes are applied, at intervals, between the rubbing surfaces, as are the oils.

The most widely known of the former class is "metalline," a material of a composition which is variable, and is determined by the conditions to which it is to be subjected. It is made, usually, by grinding the various ingredients to an impalpable powder, mixing them according to certain definite formulæ, which are the direct result of experiment, and subjecting the mass to great hydraulic pressure in chilled steel molds. From these last the metalline emerges in the form of a short rod or plug, from one-eighth to five-sixteenths inch in diameter, in condition sometimes soft enough to be readily indented by the nail, sometimes so hard as to require a knife to cut it; and in all intermediate stages. It looks like black-lead, but is more unctuous, and somewhat lighter in color. To insert it, the box or gib, for example, is bored with shallow holes, these being made with a square-ended bit, in order to leave a flat bottom. Their depth is about three-sixteenths of an inch. Into these the metalline is inserted, the diameter of the plugs being sufficient to insure a tight fit, and the surface is smoothly reamed off. Such a preparation often reduces friction, and prevents serious heating or abrasion, while presenting, in some cases, the very great advantage of freedom from the objections which are peculiar to, and inseparable from, the use of oil or any grease.*

Plumbago is used generally by interposition, although sometimes forming an ingredient in the composition of anti-friction and "anti-attrition" compounds of the first class. It should always be absolutely pure and free from grit, and should be ground to the condition of a flaky powder.† Some

* *Iron Age.*

† *American Machinist*, November, 1877, p. 3.

engineers express a preference for soapstone powder, in the form of dust, as a lubricant for the journals of machinery. For this purpose, it is first reduced to a very fine powder, then washed to remove all gritty particles, then steeped for a short period in dilute muriatic acid, in which it is stirred until all particles of iron which it contains are dissolved. The powder is then washed in pure water again to remove all traces of acid, after which it is dried, and is the purified steatite powder used for lubrication. It is not generally used alone, but is mixed with oils and fats in the proportion of about 35 per cent. of the powder added to paraffine, rape, or other oil; or the powder may be mixed with any of the soapy compounds employed in the lubrication of heavy machinery.

209. Purifying Oils.—Oils which have been once used should be carefully cleansed before being again applied to bearings. The following is a good method of purifying lubricating oil: A tub holding 16 gallons (73 litres) has a tap inserted close to the bottom, and another about 4 inches (10.16 centimetres) higher. In this receptacle are placed 7 quarts (7.94 litres) boiling water, 3½ ounces (0.09 kilogrammes) carbonate of soda, 3½ ounces (0.09 kilogrammes) chloride of calcium, and 9 ounces (0.23 kilogrammes) common salt. When all these are in solution, 45 quarts (51 litres) of the oil to be purified are let in and well stirred for five or ten minutes; the whole is then left for a week in a warm place, at the expiration of which time the clear pure oil can be drawn off through the upper tap without disturbing the bottom.

Dr. Dotch communicates to the *Scientific American* the following method and proportions for refining crude cotton-seed oil: 100 gallons (454 litres) of the crude oil are placed in a tank, and 3 gallons (13.6 litres) of caustic potash lye, of 45° Baumé, are gradually added and well stirred for several hours; or the same quantity of oil is treated with about 6 gallons (27.2 litres) of soda lye, of 25° or 30° Baumé, and heated for an hour or more to about 200° or 240° Fahr. (93° to 115° C.) under constant stirring, and left to settle. The clear yellow oil is then separated from the brown soap stock, and this dark soap sediment is placed in bags, where the re-

mainder of the oil will drain off, as the sediment has a small market value to soap-makers. The potash-lye must be made in iron pots, but the oil and lye may be mixed in wooden tanks.

210. The Pressure *which may be permitted* upon rubbing surfaces is determined by the velocity of rubbing, the character of the lubricant, and the nature of the surfaces themselves. The two surfaces should usually differ—the one being hard enough to bear the maximum pressure without change of form, and the other being less hard, in order that it may not abrade the first. With such an arrangement, the surfaces, if properly cared for, take a fine, smooth, mirror-like polish, and give a minimum frictional resistance. Cast-iron surfaces, unless very large, are less satisfactory than good wrought-iron, and moderately hard steel is much better still. A pressure of 800 pounds to the square inch (56 kilogrammes per square centimetre) can rarely be attained on wrought-iron at even low speeds, while 1,200 pounds (84 kilogrammes) is not infrequently adopted on the steel crank-pins of steamboat engines; 7,000 to 9,000 pounds pressure per inch (492 to 633 kilogrammes per square centimetre) has been reached on the slow-working and rarely moved pivots of swing bridges. In the Author's practice higher pressures than 600 and 1,000 pounds per square inch (42 to 70 kilogrammes per square inch) on iron and on steel are avoided, and, for general practice, the pressure is less as the speed is greater, since the amount of heat developed is directly a measure of the amount of work done in overcoming friction, and is proportional to the speed as well as to the pressure.

211. Size of Journals.—By a comparison of the behavior of the journals of the engines of naval steamers in 1862, the author determined the following formula for the size of journals for such engines and for stationary steam engines:

$$l = \frac{PV}{ad}, \quad \ldots\ldots\ldots \quad (8).$$

in which a is a coefficient—about 60,000 in British measures, 1,300 nearly, in metric—l is the length of the journal in inches, or centimetres, P the load in pounds, or kilogrammes, and

V the velocity of rubbing in feet, or metres, per minute; d is the diameter in inches or centimetres. Rankine published, in 1865, the following as applicable to locomotive practice:

$$l = \frac{P(V + b)}{ad}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9).$$

in which a and b are about 44,800 and 20 in British, or about 1,000 and 6 in metric measures. These are intended for iron journals; those of steel may sometimes work well if of one-half the length given by the formulas.

The length being known, the pressure per square inch admissible is:

$$p = \frac{a}{V} \quad \text{(Author)}, \quad . \quad . \quad . \quad . \quad (10).$$

or,

$$p = \frac{a}{V} + b \quad \text{(Rankine)}. \quad . \quad . \quad (11).$$

Where journals are exposed to dust or severe usage, as in locomotives, it is advisable to make them of greater length than in ordinary practice. This difference is observed in the two formulas just given. The best makers of mill-shafting make the journals about four diameters long.

212. Oiling Journals.—It is evident that the method of supplying the lubricant has an important influence on the economy of its use. A perfectly uniform supply of the minimum safe quantity enables an economy to be attained which is surprising to one who has not measured the quantity of oil used. Some years ago a distinguished firm of tool builders found that the hangers of their line shafting were working perfectly with but 34 drops of oil each per week.

The Author has often used a wire bent into syphon shape and loosely wound with lamp wick in the old fashioned oil cups. A little experimenting determines just how many strands of wick should be used, and just how low the oil can be permitted to run down in the cup, and the minimum expenditure is thus reached. The syphons were always removed when the engine was stopped for any length of time, to prevent expenditure of oil when it was not needed.

Another good arrangement for very large and important journals is an oil-pump taking oil from a reservoir into which it returns from the journal. Self-oiling boxes are still another and a more familiar device.

From what has already been said it is seen that what is a good lubricant for one purpose is not necessarily good for another. Water is valuable on the lignum vitæ sheath in the stern-bearing of the screw-shaft of a steamer, or on the wooden step of a turbine water-wheel, and answers an excellent purpose in the "*palier glissant;*" and it is the best substance known to absorb and convey away heat; but it is not a true unguent, and could not be used as such on ordinary journals.

Plumbago, tallow, and castor oil have the "body" needed for extremely high pressures; and sperm oil is the best known lubricant for general purposes; but only an oil having the purity and limpidity of watch oil will answer for watch work. The heavy oil would produce too great resistance by its viscosity to be suitable for light work, and the watch oil would be unable to sustain the pressure in heavy work.

With oils of little "body" the greatest care should be taken to secure perfect regularity of supply and to feed the least amount consistent with safety. Heavier oils should be fed more rapidly, and tallow and the greases are usually supplied as fast as the journal will take them.

213. The Modern Methods of Testing Oils are directed to the determination of a number of independent facts. These objects are:

(1.) Their identification and the detection of adulteration.
(2.) The measurement of density.
(3.) The determination of their viscosity.
(4.) The detection of tendency to gum.
(5.) The determination of temperatures of decomposition, vaporization, and ignition.
(6.) The detection of acidity.
(7.) The measurement of the coefficient of friction.
(8.) The determination of their endurance, and their power of keeping the surfaces cool.

214. Identification.—It is sometimes sufficient for the user of an oil to identify it and to be able to detect adulterations. Sperm and lard oils, for example, are standard lubricants; and if the consumer or dealer can assure himself that the oil which he has in hand is pure sperm or pure lard, that is often enough, since long experience may have taught him that this oil, and no other, is likely to fully answer his purpose. Cases sometimes occur in which the purchaser of an oil does not care to try if other less well known oils may not meet his wants quite as well and at lower cost.

The tests for identification are chemical and physical. The chemist can, sometimes, by applying "re-agents" which have peculiar effect on an oil, determine whether that oil is sperm, or lard, or other, and detect adulterations. This is in some cases quite easy to do and tolerably certain, since there are usually very few oils of which the cost would be low enough to permit their use as adulterants. For example, the chemist would look for cotton-seed oil, perhaps, in his tests of so-called *pure* lard oil, since that, in the usual condition of the market, is about as likely to be used as an adulterant of lard as any other oil. This kind of test would rarely be used except by an expert chemist, and it is enough to describe a few of the best known.

215. Chemical Methods.—Professors Grace-Calvert, Cailletet, Chateau, Waltz, and many other chemists, have systematically studied the reactions of oils with various chemicals, with a view to their identification and the detection of adulteration.

MM. Chevreul and Braconnot (1813) were probably the first to determine with satisfactory accuracy the composition of fatty substances. They found them to be thus composed:

ANIMAL.			VEGETABLE.		
	Margarine.	Oleine.		Margarine.	Oleine.
Mutton tallow.....	80	20	Colza oil	46	54
Beef tallow.....	80	30	Olive oil.....	28	72
Lard.....	38	62	Almond oil.....	24	76

Chevreul and T. de Saussure determined the elementary composition of several of these bodies thus:

TABLE XLVI.

COMPOSITION OF OILS.

	CARBON.	HYDROGEN.	OXYGEN.
Sheep's fat	79.0	11.7	9.3
Lard	79.0	11.1	9.8
Human fat	79.0	11.4	9.6
Nut oil	77.0	10.5	9.1
Almond oil	77.4	11.5	10.8
Linseed oil	76.0	11.3	12.6
Olive oil	77.2	13.3	9.4

216. Classification.—These fatty unguents are divided into five classes:

(1.) Oil, which is liquid at ordinary temperatures.
(2.) Butter, or thicker oil.
(3.) Tallow.
(4.) Grease.
(5.) Wax.

All have great commercial and industrial value; but the oils are far the most commonly useful.

217. Impurities in Oils.—The composition and character of these substances may be changed in several ways. They may absorb oxygen from the air, and become rancid; they may dry away, leaving a kind of varnish—like olive oil—or they may simply thicken or gum, and lose their fluidity as well as their property of burning, as they do in their natural state, without smoke. These changes are prevented by the exclusion of the air. They may also take up metals, when enclosed in metallic vessels, and thus become modified in character.

Dr. Stevenson Macadam states that in the course of a lengthened series of experimental observations on various paraffine oils his attention was directed to a certain oil which burned somewhat imperfectly. In a single night the wick of the lamp had to be changed several times, and the wicks, when charred, left a fine net-work of lead. The oil had been stored

in a tank lined with lead, and dissolved so much of the lead that its value as a luminant was destroyed. The action of the oil on tin, copper, and iron was so slight that its luminant properties were not much diminished. Zinc, however, was freely dissolved, and the oil was consequently rendered nearly as useless for illuminating purposes by it as by lead. Dr. Macadam therefore suggests that, while the vessels for the retention of paraffine oil may be safely constructed of or be lined with tin, copper, or iron, it would be preferable to use cisterns lined with enamel, for storing oil. William Watson, in a paper recently read before the British Association, describes the results of his experiments on the above subject. He finds that of all the oils examined, paraffine and castor oil have the least action on copper, and linseed and olive oil the greatest; sperm and seal oil have but a very slight action.

The tendency of an oil to act on metals varies with the proportion of free acid and kind of oil, and also with the nature of the metal. Nearly all fatty oils act more rapidly on copper than on iron. The following table shows results obtained by Mr. Watson:

TABLE XLVII.

SOLVENT ACTION OF OILS.

OILS.	IRON DISSOLVED IN 24 DAYS.	COPPER DISSOLVED IN 10 DAYS.
Almond	.0018 grain	.1030 grain
Castor	.1048 "	.....
Colza	.0800 "	.0170 "
Lard	.0250 "	.....
Linseed	.0050 "	.3000 "
Neats'-foot	.0875 "	.1100 "
Olive	.0062 "	.2200 "
Paraffine	.0045 "	.0015 "
Seal	.0050 "	.0485 "
Sperm	.0460 "	.0030 "

Detection of Metals and Acids.—To detect the presence of copper, mix a small portion of the oil with twice its weight of nitric acid in a test-tube, and shake well, then, separating

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the acid from the oil, add ammonia to the former; if copper is present the reaction will give a blue color by the formation of an ammoniacal solution of that metal.

To detect lead, add to a portion of the oil, contained in a test-tube, a small quantity of sulphuric acid, of carbonate of soda, or of caustic soda; if lead is present, the solution will become white and will yield a precipitate of similar color; to insure certainty, add to the solution caustic soda until the acid, if used, is neutralized, or of acid, if soda has been used, a few drops of sulphur solution, the presence of lead will be indicated by a dark brown precipitate; with bichromate of potassium or the iodide of potassium, a yellow precipitate is found.

To test lubricating oil for acid, dissolve a crystallized piece of carbonate of soda about as large as a walnut in an equal bulk of water, and place the solution in a flask with some of the oil. If, on settling after thorough agitation, a large quantity of precipitate forms, the oil should be rejected as impure.

218. **Adulterations.**—Good oils are adulterated by the addition of cheaper oils. These adulterations are detected by changes of density, or of freezing point, by differences produced in temperature on the addition of concentrated sulphuric acid, and by the reaction produced by the addition to the oil of various chemical re-agents, and, finally, by the senses of touch, taste, and smell.

The latter method presupposes great familiarity with and experience in the use of oils, and can be practiced with satisfactory results, usually, only by experts. Some oils are, however, so characteristic in taste and odor that a novice may readily recognize them. It is always best to compare the suspected oil with a sample of known purity. The characteristic odor of an oil can be brought out more strongly by warming it. The taste, odor, and feeling of the oil are sometimes considerably modified by the locality whence it is obtained, by the season during which it is prepared, and by the method of manufacture.

219. **Oleometry.**—The first of the physical tests, which tests may precede chemical analysis, is the determination of density. This is, perhaps, the simplest and easiest method of

identifying a standard oil, although by no means a certain one. This may be done by carefully weighing an exactly measured volume of the lubricant, and comparing its weight with the standard volume of a standard substance, or by the use of the "densimeter," or oleometer. This little instrument, generally known as the hydrometer, takes its name from the application for which it has been designed, as, for example, lactometer when used to determine the density of milk, alcoholometer when used to measure that of alcohol.

It is a glass cylinder, about ¾ or ⅞ inch in diameter and 4 or 5 inches long, having at one end a bulb loaded with shot, and at the other a small cylindrical stem suitably graduated.

Placing this instrument in a liquid, it floats upright, with the loaded end downward, and sinks to such a depth that the figure on the stem reads the density or the specific gravity of the liquid.

In using this instrument the liquid must usually have the standard temperature, say 60° Fahr. (15°.5 Cent.), as its density is considerably affected by heat or cold. Another form of hydrometer has a thermometer attached to the lower end. This is intended to assist in making corrections for a temperature above or below 60°; when the thermometer indicates a temperature above 60°, which is shown by the figure on the right side, the corresponding number opposite must be added to the indications on the scale above. If the thermometer stands below 60°, the corresponding number opposite must be deducted.

220. Specific Gravity of Oil.—The specific gravity of any substance is proportional to its density, and is the ratio of the weight of a given volume of the substance to that of an equal volume of water, both being taken at the temperature of maximum density of the latter. The density may also be measured by any other standard. These oleometers are often—in fact, usually—graduated by the system of Beaumé, in which $\frac{140}{130 + B^\circ}$ = specific gravity, and $\frac{140}{\text{sp. gr.}} - 130 = B^\circ$, the reading of Beaumé.

The more accurate method of determining specific gravity by weighing on the chemist's balance, has been frequently

TABLE XLVIII.

SPECIFIC GRAVITY OF OILS.—STILLWELL.

Coef. of exp. = .00063 for 1° Cent.
= .00035 for 1° Fahr.

	15° CENT. 59° FAHR.
Sperm, bleached, winter	.8813
" natural, winter	.8813
Elaine	.9011
Red, saponified	.9016
Palm	.9046
Tallow	.9137
Neats'-foot	.9142
Rape-seed, white, winter	.9144
Olive, light greenish yellow	.9144
Olive, dark green	.9145
Peanut	.9154
Olive, virgin, very light yellow	.9163
Rape-seed, dark yellow	.9168
Olive, virgin, dark clear yellow	.9169
Lard, winter	.9175
Sea elephant	.9199
Tanners' (cod)	.9205
Cotton-seed, raw	.9224
Cotton-seed, refined, yellow	.9230
Salad (cotton-seed)	.9231
Labrador (cod)	.9237
Poppy	.9244
Seal, natural	.9246
Cocoanut	.9250
Whale, natural, winter	.9254
" bleached, winter	.9258
Cod-liver, pure	.9270
Seal, racked	.9286
Cotton-seed, white, winter	.9288
Straits (cod)	.9290
Menhaden, dark	.9292
Linseed, raw	.9299
Bank (cod)	.9320
Menhaden, light	.9325
Porgy	.9332
Linseed, boiled	.9411
Castor, pure cold-pressed	.9667
Rosin, third run	9887

adopted. A standard temperature is usually taken, and all results reduced to standard by first determining the coefficient of expansion, which, for pure olive oil, has been determined by Mr. C. M. Stillwell to be 0.00063 for 1° Cent., or 0.00035 per degree Fahr. Oils often differ considerably in density, although nominally the same. The preceding table contains Stillwell's determinations.

Now, determining the gravity of an oil, sperm, for example, and finding it to be 0.8750, of 30° Beaumé, it would be at once concluded to be impure; because sperm should give about 0.8810 or 0.8815, corresponding to 29° B.

There are many forms of the oleometer, nearly all, however, having the same general character.

221. The Mineral Oils are usually lighter than those of animal or vegetable origin. Crude Pennsylvania petroleum has a composition:*

Carbon	84
Hydrogen	14
Oxygen	2
	100

The average density of petroleum is about 45° B., and it is composed of a considerable number of compounds which vaporize at temperatures varying from 32° to 700° Fahr. (0° to 370° Cent.). The following are the densities of these oils:

TABLE XLIX.

DENSITY OF MINERAL OILS, 59° FAHR., 15° CENT.

	S. G.	B.
Rhigoline	.6220	95
Benzine	.6510	85
Naphtha	.7000	70
"	.7500	57
Illuminating oil	.8000	45
Lubricating oil (heaviest)	.8900	27
Paraffine wax	.8900	27

It will be seen, on examining the tables given later, that the density of the mineral oils increases with the temperature of ignition, and with the value of the coefficients of

* The Eames System of Furnace-working of Petroleum; by Prof. H. Wurtz; *Trans. Amer. Inst. Mining Engineers*, 1875; *Eng. and Min. Journal*, Aug., 1875; *Iron Age*, Aug., 1875; *Amer. Chem.*, Sept., 1875; London *Iron*, Sept., 1875.

friction, the latter increasing in much the higher ratio. It has a specific gravity at the standard temperature of from 0.86 to 0.90, according to the degree of concentration produced in distillation.

222. Beaume's Scale.—The following table gives degrees of Beaumé and the corresponding specific gravities in parallel columns, together with the weights of one gallon and one litre : *

TABLE L.

SPECIFIC GRAVITIES AND DENSITIES, BEAUME.

DENSITIES.		LBS. IN ONE GAL.	KILOGS. IN A LITRE.	DENSITIES.		LBS. IN ONE GAL.	KILOGS. IN A LITRE.
B.	S. G.			B.	S. G.		
10	1.0000	8.33	0.83	44	.8045	6.70	0.67
11	.9929	8.27	0.83	45	.8000	6.65	0.66
12	.9859	8.21	0.82	46	.7954	6.63	0.66
13	.9790	8.16	0.82	47	.7909	6.59	0.66
14	.9722	8.10	0.81	48	.7865	6.55	0.65
15	.9655	8.00	0.80	49	.7821	6.52	0.65
16	.9589	7.99	0.80	50	.7777	6.48	0.65
17	.9523	7.93	0.79	51	.7734	6.45	0.64
18	.9459	7.88	0.78	52	.7692	6.41	0.64
19	.9395	7.83	0.78	53	.7650		
20	.9333	7.78	0.77	54	.7608		
21	.9271	7.72	0.77	55	.7567		
22	.9210	7.67	0.76	56	.7526		
23	.9150	7.62	0.76	57	.7486		
24	.9090	7.57	0.75	58	.7446		
25	.9032	7.53	0.75	59	.7407		
26	.8974	7.48	0.74	60	.7368		
27	.8917	7.43	0.74	61	.7329		
28	.8860	7.38	0.73	62	.7290		
29	.8805	7.34	0.73	63	.7253		
30	.8750	7.29	0.72	64	.7216		
31	.8695	7.24	0.72	65	.7179		
32	.8641	7.20	0.72	66	.7142		
33	.8588	7.15	0.71	67	.7106		
34	.8536	7.11	0.71	68	.7007		
35	.8484	7.07	0.70	69	.7035		
36	.8433	7.03	0.70	70	.7000		
37	.8383	6.98	0.69	75	.6829		
38	.8333	6.94	0.69	80	.6666		
39	.8384	6.90	0.68	85	.6511		
40	.8235	6.86	0.68	90	.6363		
41	.8187	6.82	0.68	95	.6222		
42	.8139	6.78		100	.6087		
43	.8092	6.74					

* For valuable tables, see Prof. S. A. Lattimore's Computation Tables, Rochester, 1872.

223. Conductivity.—Rousseau has shown that the oils, with the exception of olive oil, which has nearly $\frac{1}{100}$ the conductivity of other oils, are good conductors of electricity, and has devised an instrument to detect adulterations of olive oil which is called the diagometer. The test is made by measuring their conductivity. The instruments used are simply a galvanometer and a small voltaic battery, the current of which is passed through a small drop of the oil to be tested, and its intensity is then measured by the galvanometer. A comparison with known oils gives the evidence sought.

224. The Effect of Heat upon oils furnishes another means of determining their character and of detecting falsifications.

The temperature of distillation of petroleum products varies from 80° to 250° Fahr. (27° to 120° Cent.), for the naphthas, 250° to 600° Fahr. (120° to 315° Cent.) for illuminating oils, or 600° to 800° Fahr. (315° to 425° Cent.) for the heavy lubricating oils. The very best oils of the latter class have no bad odor, and only vaporize at 600° Fahr. (315° Cent.), or higher. Their density is about 27° or 28° B. (0.890 Sp. Gr.). They are rarely used unmixed with lighter oils.

225. Fire-Test.—The temperature of decomposition of the mineral oils is a good gauge of their values. An oil should not generally be used which takes fire at so low a temperature as 150° Fahr. (120° Cent.). Some of the best oils do not burn, or even give off much vapor at a temperature of 300° (150° Cent.) or more. This "fire-test" is usually made with a small piece of apparatus made especially for the purpose. It consists of a little tank, in which the oil to be tested is poured. This is placed in another larger cup, and the space between is filled with water for ordinary tests. A lamp beneath supplies the heat, and a thermometer, set in the cup, with its bulb in the oil, shows the temperature.

As the oil becomes heated, the observer occasionally applies a lighted match or taper to the opening of the cup. After a time a flash is seen when the match is applied, and the flame disappears as suddenly as it has appeared. This shows that vapor has been produced in sufficient quantity to

mix with the air above the oil, and produce an explosive mixture. The temperature now observed is called the "flashing point." At some higher temperature, if the cap is moved to one side and a match is applied, the oil takes fire and burns. This is the so-called "burning point." It may be 20 degrees or more above the flashing point.

In the Bailey fire-test apparatus the oil is heated in a small copper tank through which rises the flue within which is the flame of the lamp or gas-burner.

This vessel is filled only about three-fourths full of oil. The vapor formed rises at the centre, passing the bulb of a thermometer set at the top of the central vapor-flue, and issues laterally, and is ignited at a jet. The animal and vegetable oils do not vaporize, but decompose at high temperature.

The following are the results obtained with the first of the two kinds of apparatus described; others will be given later:

TABLE LI.

FIRE TESTS OF OILS.

OILS.	TEMPERATURES—FAHR. AND CENT.					
	FLASH.		TAKE FIRE.		BURN.	
	F.	C.	F.	C.	F.	C.
West Va. Oil.....	245°	118°	290°	143°	300°	149°
Winter Sperm.....	425°	219°	485°	252°	500°	260°
Lard.....	475°	246°	525°	274°	525°	274°

The flashing and the burning points, or the temperature of decomposition, can thus be found, and liability to injury by heat determined, or safety in the presence of fire. A determination of temperature of thickening or congelation will show whether oil may be used for out-of-door applications in cold climates. The standard animal and vegetable oils, and all mineral oils of good "body" and density only decompose or vaporize at a temperature exceeding that of the steam in ordinary steam engines, and the latter sometimes, and the former two usually, bear even steam at locomotive

pressure. The good mineral oils do not congeal at any ordinarily low temperatures, the heavier oils freezing at 20° Fahr. (– 7° Cent.) and the lighter remaining liquid at the freezing point. Summer sperm thickens at about 65° Fahr., freezing at about 50°, winter sperm at about 50° and 35°; and lard oil begins to harden at 40°, solidifying at 25° Fahr.

226. Oleography.—Still another, and a very beautiful, although rarely practiced, method of identifying oils of various kinds, is that introduced many years ago by Professor Tomlinson, who first applied it to the exhibition of the characteristic differences between the essential oils, and termed the peculiar and beautiful forms thus produced "cohesion figures."

It was again brought forward by Dr. Moffat,* and by him applied to the identification of the commercial oils and the detection of adulteration. The process, as perfected by Dr. Moffat, is now familiar under the name of "oleograph tests." We proceed thus: Wash out a large basin very carefully with water and alkali until it is chemically free from foreign matter, and fill with perfectly clean water. When the surface has become quiet, drop upon it a single drop of the oil to be examined. The oil at once spreads rapidly over the surface of the water in an exceedingly thin film. Presently the film commences breaking up, small openings appearing through it, which gradually enlarge and group themselves into peculiar lace-like patterns. These lace-patterns continue changing, and finally the surface is covered with detached and very minute particles of oil. Each oil, under the same set of standard conditions, exhibits a peculiar behavior which is always characteristic of the oil, and which can therefore be made of use in identifying it. Each oil spreads at a certain rate, and each, *at a given instant* during the process of change, forms a peculiar and characteristic lace. A comparison of the pattern produced in testing the several oils, and of the times of observation enables the experimenter to judge, by comparison with his standards, whether the oils tested in this way are pure or adulterated.

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* *Chemical News*, vol. XVIII, p. 299.

In doing this work, it is important to be able to secure copies of the patterns thus obtained. This is done by a very simple and neat process: Provide another basin containing water rather strongly colored with ink, and a quantity of white blotting-paper cut into pieces of such size and shape that they can be laid upon the surface of the water in the testing basin.

The observer stands, watch in hand, noting the changes progressing in the film of oil. At the proper moment—a half-minute, a minute, or two minutes, whichever may have been found a proper standard time, measured from the falling of the drop—he carefully and quickly lays a piece of his blotting-paper down on the film; then as quickly and carefully transfers it to the surface of the ink solution. At the first contact every point in the surface transfers to the paper a particle of water or a particle of oil, and the lace-pattern is now present on the paper in oil and water. On placing the blotting-paper on the colored water, all parts of the surface unprotected by oil are stained, while the rest remains uncolored, and the beautiful lace-pattern appears in black and white in permanent and preservable form. The sheet is next marked with the name of the oil, the date of the test, and the time allowed for the formation of the pattern. It still remains to be determined by further experiment how far the method may be made practically valuable and reliable.

The special precautions to be observed in practicing this method of test are to secure an absolutely perfect cleanliness of the vessels used, and to note with care that oleographic figure which is most thoroughly characteristic of the oil under test; this is found to occur at one instant during the uninterrupted process of change of each film of oil, and the patterns which precede and which succeed it are comparatively valueless.

The vessels should be cleaned perfectly with a solution of caustic potash or soda after each experiment. The oil should be let fall in a single drop upon the exact centre of the surface of water from a glass rod, and in such a manner that no disturbance is produced. These rods, when not in use, should be kept in a solution of caustic potash, and, when used

should be drawn through clear water and wiped upon a clean cloth before dipping them in the oil.

Occasionally, when the vessels have been some time in use, it will be necessary to wash them and the rods in strong sulphuric acid;* they should then be thoroughly rinsed.

The symmetry of the figures produced, as well as their characteristic form, is injured or destroyed by adulteration, and sometimes by physical changes occurring under exposure to air, and with age. Solid carbolic acid and camphor treated in this manner yield curiously active spots and figures.

The time at which the distinctive figure is formed is an absolutely essential element, as already stated, and it is therefore always advisable to first prepare a set of standards by obtaining oils of known purity and taking off oleographs, at intervals of ten seconds or of one minute, according to the rapidity of change, and this series should be preserved for comparison with the results of test of suspected oils.

Dr. Moffat thus made up an oleograph album of standards. In the series for each oil, the most thoroughly characteristic figure should be given some distinguishing mark, or otherwise identified. The oleographs may be given any desired color by using, instead of ink, a solution of the color desired. They may be readily photographed, or they may be transferred to stone.

227. Gumming and Drying.—Still another special physical test determines the degree to which the oil is liable to injury by gumming. The usual method is that of Nasmyth, who uses this very simple mode of determining the viscosity and the rate of "gumming" of oils: He places a drop at the top of an inclined plane, and notes the time required for it to run down the plane. Of oils which do not gum, the least viscous reach the bottom first; drying and gumming oils are retarded in proportion to the rate of drying or of gumming. He uses a plate of iron, 4 inches (10.2 cm.) by 6 feet (1.8 metres) on the upper surface of which six equal-sized grooves are planed. This plate is placed in an inclined posi-

* *Chemical News*, vol. XIV., p. 46.

tion, falling one inch in six feet. The mode of testing is as follows: Assume that there are six varieties of oil to test, and it is desired to know which of them will, for the longest time, retain its fluidity when in contact with iron and exposed to the action of air; the investigator pours out *simultaneously*, at the upper end of each inclined groove, an equal quantity of each of the oils under examination. This is very conveniently and correctly done by means of a row of small brass tubes. The six oils then make a start together; some get ahead the first day, and some keep ahead the second and third day, but on the fourth or fifth day the bad oils, whatever good progress they may have made at the outset, come to a standstill by their gradual coagulation, while the good oil holds on its course; and at the end of eight or ten days there is no doubt left as to which is the best. Linseed oil, which flows rapidly *the first day*, is set fast after having traveled 18 inches, while second-class sperm passes first-class sperm 14 inches in nine days, having traversed in that time 5 feet 8 inches down the hill. The following table shows the state of the oils after a nine days' run :*

TABLE LII.

FLUIDITY OF OILS.

DESCRIPTION OF OIL.	FIRST DAY.	SECOND DAY.	THIRD DAY.	FOURTH DAY.	FIFTH DAY.	SIXTH DAY.	SEVENTH DAY.	EIGHTH DAY.	NINTH DAY.
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
Best sperm oil.....	2 8½	4.2	4.5¾	4.6	4.6	4.6	4.6⅓	stat.	.....
Common sperm oil.....	1.7	3.9	4.6¾	4.11	5.1½	5.4	5.6¾	5.7⅜	5.8
Gallipoli oil.....	0.10¼	1.2½	1.6	1.6⅛	1.7⅝	1.8¾	1.9	1.9¼	1.9½
Lard oil.....	0.10¼	0.0½	0.10¾	0.10¾	0.11¾	stat.	.....	.....	.....
Rape oil.....	1.2½	1.6¼	1.7	1.7⅓	1.7¼	1.7¼	1.7¼	1.7¾	stat.
Linseed oil.....	1.5½	1.6	1.6¾	1.6¾	1.6⅔	1.6¼	1.6¼	stat.	.....

A modified apparatus is described by Mr. W. H. Bailey.† It consists of a piece of plate-glass set with considerable

* Appleton's *Dictionary of Mechanics*, vol. II. † *Friction and Lubrication*, p. 88.

inclination, and heated, by means of a vessel of boiling water, to about 200° Fahr. (93° Cent.), and held at a uniform temperature, as indicated by the thermometer attached. A drop of oil placed at the top will flow down a few inches, as in Napier's test, and, if permitted to remain upon the glass some days, will give evidence of any tendency to gum. A scale on the side of the box affords a convenient means of measuring the track of the flowing drop. Watch oil is tested in Switzerland somewhat similarly. If the oil is found to become decidedly resinous after two or three days' exposure to heat, it is condemned.

Still another method is that in which the oils, at a stand ard temperature, are allowed to flow from a vessel, kept filled to a uniform depth, through an orifice of standard size. The amount discharged will be greater the more fluid the oil; or the vessel may be of any convenient capacity, or may have any standard volume of oil put into it, and the time required to empty it may be observed. The most accurate work is done, probably, by enclosing a pipette in a water jacket, and thus keeping the temperature under control by circulating water through this jacket at any desired temperature. In Woodbury's experiments,* the capacity of the pipette was 25 cubic centimetres, the orifice measuring .039 inch (0.1 centimetre) in diameter. At low temperatures, the fluidity increased faster than the coefficients of friction decreased, became nearly proportional at, and a little above, usual atmospheric temperature, and increased less rapidly at high temperatures. The pipette became empty, as follows: lard oil, at 70° Fahr. (21° Cent.) in 682 seconds; sperm, 266 to 280 seconds; neats'-foot, 840 seconds; heavy mineral oil, 554 seconds; light oil, 250 seconds. Coleman found that while sperm flowed through a funnel in 5 minutes, a mineral oil required but 3 minutes, and lard took 7 minutes; a mixture of mineral oil and lard in equal parts, ran through at the same rate as sperm; rape required 8 minutes, seal oil 6½, and neats'-foot 8½ minutes.

228. **Chemical Methods of Test** have been proposed in

* *Trans. Am. Soc. Mech. Eng'rs*, 1880.

great variety. In general the chemist first compares the density of the oil to be examined with that of the standard pure oil of the same denomination as given in the printed tables.

Animal and vegetable oils are distinguished by the fact that chlorine turns animal oils brown and vegetable oils white.* Some special tests are quite reliable for certain adulterations, and chemists have devoted much time to their discovery and to perfecting methods.†

Among the most common mixtures are the adulteration of sperm with blackfish or with whale oil; the mixture of cotton seed with otherwise good lard; the introduction of peanut (ground nut or earth nut) oil with olive; and the addition of an alkali with water, or of plaster to tallow. Probably the greater proportion of the lubricating oils now in use are mixtures, and the most usual is an acknowledged mixture of mineral with animal oils.

229. Machines for Testing Lubricants.—The most important of all the tests to be applied to determine the precise value of a lubricating material, and that which most completely and satisfactorily reveals that value, is applied by using some form of apparatus or machine specially constructed for the purpose.

In order to determine precisely what oils are adapted to any special purpose, or to ascertain for what uses any oil is best fitted, it is always necessary to make an examination of the lubricant working under the specified conditions. That is to say, the oil should be put upon a journal of the character of that on which it is proposed to use it, and, subjecting it to the maximum pressure proposed, running it at the maximum speed that the journal is ever expected to attain; its behavior will then show conclusively its adaptability to such an application. While running, it is necessary to be able to measure the friction produced, and to determine its coefficient, which, as we have seen, is its measure, and to be able to note its durability and the rise in temperature of the bearing.

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* *Moniteur des Produits Comique*, 1875.

† See *Treatise on Friction and Lubrication* (N. Y., 1879), for a more complete account.

These qualities being determined and recorded, all is known of the oil that is needed to determine its lubricating power.

As already stated, lubricants are tested to determine their value by placing them as nearly as possible under the conditions of actual work in machines designed for this purpose. A considerable number have been invented, although but two or three are in use.

A machine which has been well known abroad for many years, and has recently been introduced to some extent in the United States, is that of Messrs. Ingham & Stapfer. It consists of a shaft running in two bearings and carrying a third journal between them. This latter has adjustable bearings, which are set up to any desired pressure by weighted levers. A thermometer in the top brass enables the heating of the bearing to be observed. In this machine the friction cannot be measured; but the durability of an oil and its effectiveness in keeping a bearing cool can be observed. The machine has been extensively used in Europe, where Messrs. Bailey & Co., of Salford, have been building it many years. A somewhat similar but much larger machine has long been used at the Brooklyn Navy Yard, and an elaborate investigation was made there by Messrs. King, Stivers, and Price, of the United States Navy Engineer Corps.

The work done on the Ingham & Stapfer machine is sometimes plotted as in the accompanying diagram:

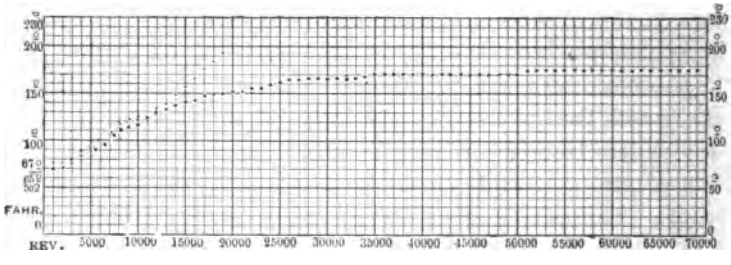

FIG. 57.—OIL TEST. HEAT AND WORK.

The two dotted lines show the behavior of two different samples of oil under test. The line of large dots shows an excellent quality of prepared and purified sperm, that, start-

ing at a temperature of 67° Fahr. (19°.5 Cent.), has, with 70,000 revolutions, only attained 176° (80° Cent.); while the other, an indifferent mixed oil, attains 200° (93°.3 Cent.), with only 19,000 revolutions. By means of such a diagram a permanent record of all tests can be kept for future guidance.

230. Thurston's Oil-Testing Machines.—The construction of a machine devised by the Author is best shown in Figs. 58 and 59, below.

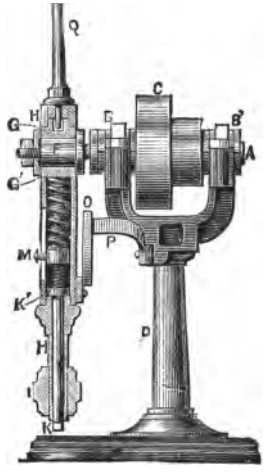

FIG. 58.

At *F* is the journal on which the lubricating material is to be placed for test. This journal is on the overhung extremity of shaft *A*, which is carried in bearings, *BB'*, on a standard, *DD'*, mounted on a base plate, *EE'*. The shaft is driven by a pulley, *C*, at any desired speed. A counter is placed at the rear end of the shaft to indicate the number of revolutions. Usually, the shaft is driven at a fixed speed, corresponding to the velocity of rubbing surfaces approximating that of journals on which it is proposed to use the oil. The testing journal, *F*, is grasped by bearings of bronze, *GG'*, and with a pressure which is adjusted by the compression of a helical spring, *J*. This spring is carefully regulated, and the total pressure on the journal and the pressure per square inch are both shown on the index plate, *NN'*, by a pointer, *M*. Above the journal is a thermometer, *QQ'*, of which the bulb enters a cavity in the top "brass," and which indicates the rise in temperature as wear progresses.

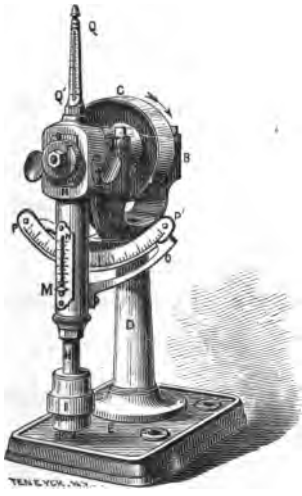

FIG. 59.

The "brasses," thermometer and spring are carried in a pendulum, H, to which the ball, I, is fitted; and the weights are nicely adjusted in such a manner, that the maximum friction of a dry but smooth bearing shall just swing it out into the horizontal line. The stem, KK', of the screw, which compresses the spring, projects from the lower end of the pendulum, and can be turned by a wrench. A pointer, O, traverses an arc, PP', and indicates the angle assumed by the pendulum at any moment. This angle is large with great friction, and very small with good lubricating materials. This arc is carefully laid off in such divisions, that dividing the reading by the pressure shown on the index, NN', gives the corresponding coëfficient of friction.

The figures on the arc are the measure of the actual resistance of friction on the surface of the journal in pounds. Dividing this frictional resistance by the total load gives, as by the definition originally given, the exact value of the coefficient. As there is no intermediate mechanism, this measure is obtained without possible error, and, as the resisting moment changes very rapidly at low angles, great precision of measurement is obtained, as will be seen when the results of experiment are stated. The machine can also be arranged to give readings of this coefficient directly.

231. **The Theory of the Machine** is as follows:

Let R = radius to centre of gravity of pendulum;
F = effort due to weight of arm;
r = radius of journal;
l = length of journal;
w = weight of pendulum complete;
P = total pressure on journal (top and bottom);
p = pressure per square inch of longitudinal section;
T = tension on spring;
Θ = angle between arm and a perpendicular through axis;
f = coefficient of friction;
Q = total friction.

When Θ is equal to 90°,

$$FR = Qr \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12).$$

And when any other angle,

$$FR \sin \Theta = Qr \quad . \quad . \quad . \quad . \quad . \quad . \quad (13).$$

Solving equation (13) with respect to Q,

$$Q = \frac{FR \sin \Theta}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14).$$

The coefficient of friction is

$$f = \frac{FR \sin \Theta}{rP} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15).$$

The pressure per square inch is

$$p = \frac{P}{4lr} = \frac{2\,T + w}{4lr} \quad . \quad . \quad . \quad . \quad (16).$$

From this last equation the graduations on the right-hand side of the index-plate are deduced.

From the equation

$$N = 4plr \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17).$$

the numbers on the left-hand side are determined.

By substituting in equation (12) the value of Q, in terms of the coefficient and total pressure, from (15) and (16), it becomes

$$FR = f\,(4plr)\,r \quad . \quad . \quad . \quad . \quad . \quad . \quad (18).$$

Solving with respect to f, equation (18) becomes

$$f = \frac{\frac{FR}{r}}{4plr} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19).$$

From the numerator of the second number of equation (19) the graduations on the arc are deduced.

In applying the foregoing equations to the machine seen in figures 58 and 59, and the following numerical values may be given to the respective symbols:

$F = 2.5$ lbs.; $R = 10$ in.; $r = 0.625$ in.; $l = 1.5$ in.; $4lr = 3.75$ sq. in.; $w = 6$ lbs. Also, a compression of 1⅜ inches of the spring corresponds to a tension of 100 pounds; hence, for each pound's tension the spring will be compressed 0.01375 of an inch.

The graduations on the right-hand side of the scale are obtained from equation (16):

$$p = \frac{2\,T + w}{4lr} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20).$$

The first graduation will naturally be that value of p when T is equal to 0, which value is 1.6.

The speed of the machine, when the belt is upon the largest pulley of the cone, C, should be that which will give at the surface of the testing journal the least speed of rubbing, which is usually to be adopted.

The figures on the arc PP', traversed by the pointer O, attached to the pendulum, are such that the quotient of the reading on the arc PP', by the total pressure read from the front of the pendulum at MN, gives the "coefficients of friction." A printed table, furnished with each machine, gives these coefficients for a wide range of pressures and arc-readings.

232. To determine Lubricating Quality, the pendulum, HH, is removed from the testing journal GG'; the machine is adjusted to run at the desired pressure, by turning the screw-head K, projecting from the lower end of the pendulum, until the index M above shows the right pressure, and to run at the required speed by placing the belt on the right pulley C.

The bearings are then spread apart by means of the two little cams on the head of the pendulum H, in the small machine, or by setting down the brass nut immediately under the head in the large machine, and the pendulum is placed

upon the testing journal GG', seeing that no scratching of journal or brasses takes place. Then the journal is oiled through the oil cups or the oil holes, and the machine set in motion, running it a moment until the oil is well distributed over the journal.

Next the machine is stopped; the nuts or the cams which confine the spring are loosened, and, when it is fairly in contact and bearing on the lower brass with full pressure, are turned fairly out of contact, so that the spring may not be jammed by their shaking back while working. The machine is started again and run until the behavior of the oil is determined, keeping up a free feed throughout the experiment.

At intervals of one or more minutes, as may prove most satisfactory, observations and records are made of the temperature given by the thermometer, QQ, and the reading indicated on the arc P, of the machine, by the pointer O. When both readings have ceased to vary, the experiment may be terminated. The pendulum is then removed, the pressure of the spring being first relieved, and the journal and brasses cleaned with exceedingly great care from every sign of grease; special care is taken to have no particle of lint on either surface, or any grease in the oil cups or oil passages.

A comparison of the results thus obtained with several oils will show their relative values as reducers of friction. If the lubricant is to be used at high temperatures, a corresponding temperature is given to the bearings by means of a Bunsen flame.

233. Steam-Cylinder Lubricants are tested upon bearings heated to a temperature corresponding to any desired steam pressure. When the maximum temperature has been attained, the flame is removed, and the behavior of the oil noted as the temperature falls to the boiling point, which corresponds to atmospheric pressure or to zero on the steam gauge. Any effervescence or excessive friction at higher temperatures condemns the lubricant. For comparison, it it customary to take the average of the coefficients of friction for temperatures ranging from 340° Fahr. (171° C.)—corre-

sponding to a gauge pressure of 7 atmospheres—to 212° Fahr. (100° C.)

Results are recorded in tables furnished on blanks—of which a copy is given below—which are sent with the machine, thus :

(1.) The pressure and speed of rubbing at each trial ; (2.) The observed temperatures ; (3.) The readings on the arc of the machine ; (4.) The calculated coefficients of friction.

RECORD OF TESTS OF LUBRICANTS.

LABORATORY NO..... ORIGINAL MARK..... SOURCE.....

Composition.....
.....
.....
.....
Investigation.....
.....
.....
.....

Coefficient of Friction = $\frac{\text{Friction in Pounds}}{\text{Total Pressure.}}$

No. of Test.....
Pressure on Journal, lbs. per sq. inch.....
Total Pressure on Journal, lbs.....
Amount of Oil used on Journal, mg.....
Average Coefficient of Friction.....
Minimum Coefficient of Friction.....
Total No. of Revolutions.....
Total No. of Feet traveled by rubbing surface.....
Elevation of Temperature, max.....

TIME, MINUTES.	REVOLUTIONS.	TEMPERATURE.	FRICTION, POUNDS.	COEFFICIENT OF FRICTION.	TIME, MINUTES.	REVOLUTIONS.	TEMPERATURE.	FRICTION, POUNDS.	COEFFICIENT OF FRICTION.	TIME, MINUTES.	REVOLUTIONS.	TEMPERATURE.	FRICTION, POUNDS.	COEFFICIENT OF FRICTION.

At the end of the trial the average and the minimum coefficients, and the total distance *rubbed over* by the bearing surfaces are recorded.

234. To determine the Liability of the Oil to Gum.—The bearings are lubricated with a definite quantity of the oil, and the machine run a certain number of revolutions. The temperature of the bearings and the friction at the end of this period are noted. Both journal and brasses are then

removed, placed under a glass receiver which excludes the dust yet permits the entrance of air, and are left there for any desired length of time. At the end of that time the bearings are replaced in the machine, and the latter is run until the temperature of the bearings is the same as at the previous trial; the friction is then again noted. Any increase of friction above that previously observed must be due to the gumming of the lubricant. For the machine described, the standard quantity of the lubricant is 16 milligrammes, which is ample to afford perfect lubrication of the bearing surfaces during the trials. The number of revolutions at the first trial is 5,000; it may, however, vary considerably without affecting the results so long as it is too small to affect the wearing qualities of the lubricant, as within this limit the friction remains constant, with a constant temperature. Changes in temperature and friction always accompany each other; it is for this reason that great care is taken to obtain the same temperature of bearing at each trial.

235. To determine Durability, proceed as in determining the friction, except that the lubricant should not be continuously supplied, but should be fed to the bearing a small and definite portion at a time—say a drop for each two inches length of journal. Extreme care should be taken that each portion actually reaches the journal and is not lost, either in the oil-hole or by being wiped off the journal, and that the portions applied are *exactly* equal.

When the friction, as shown by the pointer *O*, has passed a minimum and begins to rise, the machine should be carefully watched, and should be stopped either at the *instant* that the friction has reached double the minimum, or when the thermometer indicates 212° Fahr. (100° C.); or else another portion of the lubricant should be then applied to the journal.

This operation should be repeated until the duration of each trial becomes nearly the same; an average may then be taken either of the time, of the number of revolutions, or of the distance rubbed over by the bearing, which average will measure the durability of that lubricant. Next carefully clean the testing-journal, and proceed as before with the next

oil to be tested. In making comparisons, the observer always tests the standard as well as the competing oils on the same journal and under *precisely* the same conditions.

When testing an oil to ascertain its "durability" or endurance, a certain quantity, which is determined by experiment, is placed upon the journal, in all cases, and the test is continued until a limit is reached which is considered by the experimenter to be that of the valuable or safe use of that quantity of the lubricant under the conditions of the trial.

Until the Author began his investigations it was the universal custom to continue the trial until the temperature of the bearing, as indicated by the thermometer, attained a certain point, as 120° or 200° Fahr. (49° to 93° Cent.), and to take the number of revolutions of the journal, or the number of feet traversed up to that point as a measure of endurance. The real endurance, however, of the lubricating material bears no definite proportion to the range of temperature thus observed.

A better method is probably that adopted by the boards of U. S. Naval Engineers, sometimes appointed to test oils at the navy yards. By this method the quantity of oil required to keep down the temperature of journal to a certain figure, as 110° or 115° Fahr., during a definite period, as one hour, five hours, or twenty-four hours, is measured, and the endurance is taken as inversely proportional to these amounts.

The Author's method is quite a different one. It considers the endurance of a lubricant to be measured by the length of time that it will continue to cover and lubricate the journal, and prevent abrasion. When an oil is placed upon a journal and there subjected to wear without renewal, it gradually assumes a pasty or gummy condition, slowly losing its lubricating power, and finally either increases friction to an objectionable extent, or oftener becomes so far expended as to permit the two rubbing surfaces to come in contact. It has been my custom to run until this occurs, and then to take the length of the run as a measure of the endurance of the oil.

It is extremely difficult to obtain successive measures of similar value by this method; but by taking an average of

several—or many, if necessary—successive trials, the true measure of the endurance of lubricants can be obtained with any desired or necessary accuracy. This method, it should be observed, involves far more risk of injury to the journal than the other, and this necessitates, sometimes, considerable loss of time in bringing the rubbing surfaces back into good condition again before going on to make other tests. The determination of the real value of the lubricant is usually of sufficient importance to justify whatever time, trouble, and expense may be thus incurred.

The observer is compelled to be exceedingly careful of the testing journal. A scratch will alter the condition, sometimes, to a measurable degree. For nice work the size of the drops is very carefully preserved constant. It is sometimes weighed on a chemist's balance. For rough work a dropper, such as is used for medicine, with careful handling, will do very well. Very good work is done by dropping the oil from a No. 8 wire, filed smoothly to rather a blunt point. Dipping it into the oil, the first drops, when held vertical, are variable, but they very soon become uniform. Use the drop that falls after the expiration of three-fourths of a minute. The wire yields drops of sperm, at that instant, weighing eight milligrammes. The operator is always careful to see that the testing journal has a little end-play in its bearings, and to keep it moving, during the test, in order to keep the oil distributed.

236. Railroad Machine.—The small machine gave such results as to encourage the Author to design a large one specially fitted for railroad work.

The journal is of standard car-axle size, 3¼ inches diameter and 7 inches long (8.3×17.8 cm.). The speed is intended to be adjusted to speeds varying from that of a 26 inch (76 cm.) engine-truck wheel at 60 miles (96 kilometres) an hour, down to that of a 42 inch (116.6 cm.) wheel running 15 miles (24 kilometres) an hour. The pressures are adjustable from a few pounds total pressure up to 400 pounds per square inch (28 kilogs per sq. cm.), or a load of nearly 10,000 pounds (4,536 kilogs.) on the journal.

Fig. 60 is a side elevation of the larger machine, with the journal and pendulum in section, and Fig. 61 a front elevation. It consists of a shaft, *A B*, which is driven by a cone pulley, *C*, the whole mounted on a cast-iron stand, *D*, terminating in a forked end at the top, with two bearings, *E* and *F*, in which the shaft runs. The shaft projects beyond the journal *F*, and the projecting part, *A*, is provided with a

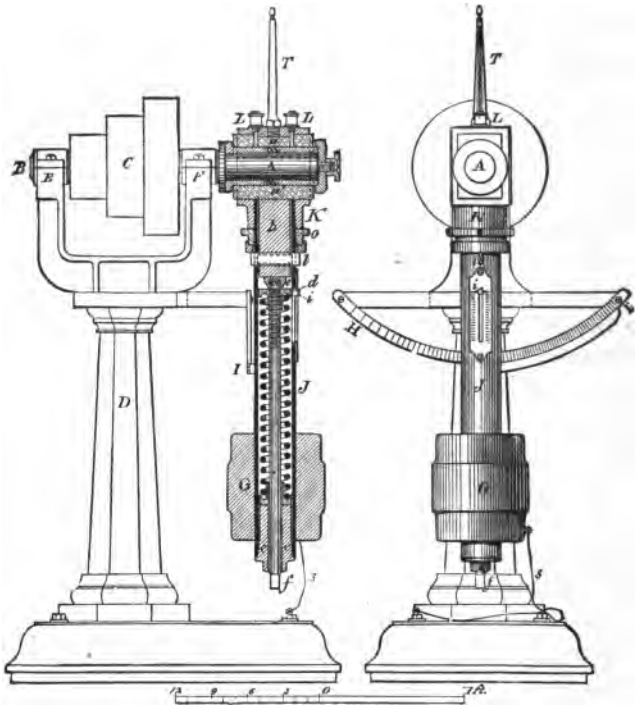

FIG. 60. FIG. 61.

sleeve or bushing, *mm*, the outside of which forms a journal on which the tests of oil are made. A pendulum, *AG*, is suspended from this journal with suitable bearings, *aa*, which work on the journal *mm*; a heavy weight, *G*, may be attached to the lower end of the pendulum, although often unnecessary. It is evident that the friction on the journal

mm will have a tendency to move the pendulum in the direction of the revolution of the shaft, and that the greater the friction on the journal, the farther will the pendulum swing. A scale or dial, *HI*, is attached to the stand, and the distance the pendulum swings may be read off on this scale, which thus indicates the coefficient of friction of the lubricant on the journal.

In order to get any desired pressure of the bearings on the journal, the pendulum is constructed as follows: A wrought-iron pipe, *J*, which is represented in Fig. 60 by solid black shading, is screwed into the head *K*, which embraces the journal and holds the bearings *aa* in their place. In this pipe a loose piece, *b*, is fitted, which bears against the under journal-bearing, *a'*. Into the lower end of the pipe a piece, *cc*, is screwed with a hole drilled in the centre, through which a rod, *J*, passes, the upper end of which is screwed into a cap, *d'*; between this cap and the lower piece, *cc*, a spiral spring, shown in section in Fig. 60, is placed. The upper end of the rod has a cap, *e*, in which it turns, and which bears against the piece *b*, which, in turn, bears against the bearing *a'*.

If the rod is turned with a wrench applied to the square head at *f*, it is obvious that the cap *d* will be either drawn down on the spiral spring, which will thus be compressed, or it will be moved upward, and the spring will thus be released, according to the direction in which the rod is turned. If the spring is compressed, its lower end will bear against the under cap and on the piece *cc*, by which the pressure will be transmitted to the pipe *J*, and thence to the head *K*, and from that on the upper journal-bearing *a*; while, at the same time, the upper end of the spring bears against the cap *d*, which, being screwed on the rod *f*, transmits its pressure upward to the cap *e*, and from that to the loose piece *b*, and from that to the upper journal-bearing, *a*. It will thus be seen that any desired pressure within the limits of the elasticity of the spiral spring may be brought upon the journal and bearings by turning the rod *f*. The piece *b* has a key, *l*, which passes through it and the pipe

J. This key bears against a nut, *o*, which is screwed on the pipe, its object being to provide a ready means of relieving the journal of pressure by simply turning the nut *o* when it is desired to do so. An index, *i*, is attached to the helical spring so as to show the position of the latter. The oil is fed to the journal by means of oil-cups, *LL*. On the top of the head *K*, a thermometer, *T*, is attached between the two cups, and from it the rise in temperature is observed. A cord, *s*, is attached to the pendulum to prevent its being thrown beyond the limits provided for it.

The machine represented by Figs. 60 and 61 is the largest size yet built, and is the one which is usually adopted in testing oil for railroads.

Some slight modifications have been made here, as in the cone pulley and in the substitution of a large relieving nut under the head of the pendulum for the two cams used to remove the load in the smaller machine: the bearings are also sometimes cast hollow, and a current of water is sent through them to secure absolute uniformity of temperature.

237. Experiments and Researches.—It will be presently seen that the friction is modified by all differences in the material of the journal and its bearings, as well as by pressure, speed of rubbing, temperature and freedom, and uniformity of lubrication, and we can therefore readily appreciate the necessity of testing the lubricant under the actual conditions proposed in its use.

The tests made by the Author, and of which some of the results are to be given, have been principally made on the smaller of the testing machines here described. They include tests of every kind of lubricant known to the engineer or the mechanic, and of very many which are not familiar, as well as of many that will never be used for this purpose.

238. Friction of Cast-iron Journals.—The following extended table exhibits the results of tests of some of these unguents. In making these tests, a cast-iron journal in good condition was used, the speed of rubbing was maintained at 750 feet (230 metres) per minute, and the same quantity of oil (32 milligrammes) was used at each trial. The results of

TABLE LIII.

COEFFICIENTS OF FRICTION ON CAST-IRON JOURNALS.

AVERAGE AND MINIMUM TEMPERATURE, 70° F. (21° C.); FEED INTERMITTENT.

NAME OF OIL.	POUNDS PRESSURE PER SQUARE INCH. KILOGRAMMES PER SQUARE CENTIMETRE.							
	8		16		32		48	
	0.56		1.1		2.2		3.4	
	AVGE.	MIN.	AVGE.	MIN.	AVGE.	MIN.	AVGE.	MIN.
GROUP I.								
Natural Summer Sperm	.1720	.1330	.1627	.1083	.102	.0833	.1180	.1050
Natural Winter Sperm	.2505	.1500	.1410	.1000	.0958	.0875	.0813	.0750
Bleached Winter Sperm	.1920	.1583	.1600	.1330	.1172	.0916	.09907	.0944
Bleached Summer Whale	.1866	.1333	1383	.09166	.1109	.0874	.0881	.0777
Natural Summer Whale	.1986	.1500	.1482	0916	.1316	.1086	.0951	.0722
Natural Winter Whale	.3296	.1833	.1902	.125	.0925	.0750	.1444	.1000
Bleached Winter Whale	.1979	.1333	.1916	.1333	.1086	.1000	.0993	.0705
Winter Lard Oil	.2386	.1666	.1575	.1166	.1405	.1000	.1005	.0750
Extra Neat's-foot Oil	.2242	.1500	.1621	.1000	.1166	.0916	.1138	.1055
Tallow Oil	.1840	.1500	.1460	.1000	.0935	.0750	.1166	.0844
Refined Seal Oil	.1585	.1333	.1378	.1083	.1190	.0916	.0986	.0750
Bleached Winter Elephant Oil	.1928	.1333	.1650	.1083	.0862	.0791	.0766	.0611
GROUP II.								
Olive Oil	.1668	.1333	.1575	.1000	.1681	.1000	.0930	.0555
Cotton Seed Salad Oil	.2156	.1577	.1757	.1250	.1444	.1083	.0996	.0694
Palm Oil	.2826	.1666	.2041	.1250	.1116	.0584	.1013	.0666
Rape Seed Oil	.1817	.1333	.1567	.1250	.1187	.0833	.1063	.0722
Elaine Oil	.2597	.2000	.1842	.1500	.1277	.0833	.1305	.1111
Linseed Oil	.1598	.1333	.1215	.0833	.1347	.0750	.0962	.0609
Peanut Oil	.1910	.1500	.1688	.1333	.10052	.0792	.0833	.0550
Refined Cotton Seed Oil	.2125	.1666	.1401	.1249	.1166	.1000	.1100	.0800
Rosin Oil	.2765	.2650	.2452	.1500	.1170	.0833	.1028	.0844
Cocoanut Oil	.1750	.1333	.1066	.0916	.1062	.0791	.0794*	.0611*
Cold Pressed Castor Oil	.2375	.1916	.1380	.1125	.1026	.0708	.0944	.0722
GROUP III.								
Labrador Cod Oil	.2475	.1500	.1488	.1250	.1016	.0666	.0805	.0661
Tanner's Cod Oil	.2776	.2166	.1666	.1500	.0970	.0833	.0880	.0833
Menhaden Oil	.2530	.1660	.1238	.1000	.1000	.0917	.1220	.1000
GROUP IV.†								
Mineral Sperm Oil	.1875	.1333	.1604	.1416	.0861	.0791	.0944	.0944
Deod. White Lubricating	.1537	.1500	.1583	.1500	.1277	.1125	.1277	.1277
Bleached Deod. Lubricating	.1833	.1333	.2333	.1500	.1250	.1166	.1222	.1222
Unbleached Deod. Lubricating	.2550	.1500	.2067	.1500	.1275	.1250	.1555	.1444
Kerosene	.2330	.2165	.1729	.1416	.1250	.1250	.1770	.1770
Crude Lubricating	.1272	.1100	.1453	.1000	.1777	.1500	.1500	.1500
Paraffine	.2607	.2000	.1777	.1333	.1343	.1125	.2222	.2222
GROUP I.	SECOND SERIES OF TESTS.							
Natural Winter Sperm	.2072	.1333	.1661	.1291	.1302	.0958	.1155	.0888
Bleached Winter Sperm	.1755	.1166	.1678	.1291	.1083	.0958	.0811	.0750
Natural Winter Whale	.2369	.2166	.1250	.1000	.1000	.0750	.0777	.0666
Bleached Winter Whale	.1747	.1333	.1483	.1133	.1333	.0833	.0916	.0666
Winter Lard	.1959	.1583	.1770	.1250	.1095	.0666	.0718	.0666
Extra Neat's-foot	.1746	.1500	.1254	.1000	.1198	.0791	.1159	.1000
GROUP II.								
Olive Oil	.1839	.1333	.1175	.0916	.0902	.0750	.1344	.0611
Refined Rape Seed (Yellow)	.1716	.1666	.1435	.1166	.1000	.0833	.0822	.0555
Winter Pressed Cotton Seed (White)	.1259	.1166	.0981	.0833	.0983	.0666	.0861	.0750
Winter Pressed Cotton Seed (White)	.1557	.1333	.1006	.0833	.0895	.0750	.0758	.0722
GROUP III.								
Menhaden Oil	.1637	.1333	.1685	.1083	.0982	.0625	.0963	.0888

* Values somewhat uncertain.

† All mineral oils here described are of uncertain composition.

two series of tests are here given. The rubbing surfaces were in *fair* condition, and it is uncertain how much gain would result from their further improvement.

Experiments made by Mr. C. J. H. Woodbury, in the lubrication of spindle frames, for the Manufacturers' Mutual Fire Insurance Company, have supplied very complete data exhibiting the behavior of oils in ordinary mill work under very light pressures.*

The following are some of the more interesting and useful figures:

TABLE LIV.

QUALITIES OF LUBRICATING OILS.

OIL.	COEFFICIENT AT 100° F., 38° C.	FLASHING POINTS.		PER CENT. LOSS BY EVAP. 12 HR.	SPEC. G. AT 100° F. 38° C.	WEIGHT.	
		F.	C.			gals. lbs.	litre grammes.
Sperm, Winter Bleached.	0.096	374°			0.884	7.4	0.73
Sperm, Winter Bleached.	0.119	304		2.25	0.887	7.4	0.73
Sperm, Winter Bleached.	0.118	440		0.47	0.883	7.4	0.73
Sperm, Winter Bleached.	0.107			0.23			
Sperm, Winter Bleached.	0.122			0.03	0.881	7.4	0.73
Sperm, Winter Bleached.	0.117			0.35	0.880	7.4	0.73
Sperm, Unbleached	0.115	400			0.884	7.4	0.73
Sperm, Unbleached	0.140	430			0.889	7.4	0.73
Lard Oil.....	0.218				0.919	7 7	0.76
Lard (No. 1) Oil.....	0.185			0.32	0.918	7.7	0.76
Lard (No. 2) Oil.....	0.187			1.25	0.918	7.7	0.76
Lard (Leaf) Oil.....	0.205			0.75	0.920	7.7	0.76
Neat's-foot Oil.....	0.194	418		0.37	0.917	7.7	0.76
Neat's-foot Oil.....	0.243	440		0.80	0.923	7.7	0.76
Seal Oil.....	0.161	486		1.40	0.926	7.7	0.76
Castor Oil.....	0.380				0.966	8.0	0.79
Mineral Oil.....	0.076	284		5.50	0.868	7.2	0.71
Mineral Oil.....	0.074	300		3.48	0 869	7.3	0.72
Mineral Oil.....	0.111	314		2.70	0.892	7.4	0.73
Mineral Oil.....	0.113	318		1.92	0.891	7.4	0.73
Mineral Oil.....	0.119	338		1.30	0.895	7.4	0.73
Mineral Oil.....	0.123	342		0.95	0.896	7.4	0.73
Mineral Oil.....	0.173	350		1.22	0.908	7.5	0.74
5 Mineral Oil, 1 Sperm.	0.119	322		2.90	0.861	7.2	0 71
5 Mineral Oil, 1 Sperm.	0.180	266		5.35	0.862	7.2	0.71

The spindles were driven at 7,600 revolutions per minute, with a band tension of 4 pounds (1.8 kilogs.)

A change of temperature from 50° to 75° F. (10° to 24° C.)

* Reported to American Society of Mechanical Engineers, *Vide* Trans. 1881.

reduced the friction over 40 per cent.; a change of band tension from 1 to 5 pounds (0.45 to 2.2 kilogs.), increased friction 229 per cent.

239. Friction with Varying Pressure.—On examination of the tables given in article 238, we are at once impressed with the immense difference which occurs with variation of pressure. It is seen that, at a pressure of 48 pounds per square inch (3.3 kilogs. per square centimetre), the values are not far from those quoted by accepted authorities, but at the lower pressures, where the resistance is more due to viscosity than to true friction, the value of the coefficient of friction immensely exceeds those familiar figures.

It is instructive to compare these figures with those obtained at high pressures, with which object we give the table below. Tested on a fine steel journal, with free lubrication, the figures become but a fraction of those already given. Sperm, lard, and West Virginia oil, thus tested, give:

TABLE LV.

COEFFICIENT OF FRICTION ON FINE STEEL JOURNALS.

NAME.	PRESSURE: POUNDS PER SQUARE INCH. KILOGRAMMES PER SQUARE CENTIMETRE.								
	4. 0.3	10. 0.7	25. 1.8	150. 10.5	200. 14.1	250. 17.5	275. 19.3	300. 21.1	500. 35.2
Sperm	0.12	0.08	0.041	0.0090	0.0096	0.0086	0.0091	0.0046	0.0033
Lard	. ..	....	0.056	0.0136	0.0127	0.0110	0.0090	0.0059	0.0044
West Virginia..	....	....	.....	0.0120	0.0095	0.0081	0.0100	.....	.....

Here it is seen that the figures are as widely different from accepted values at very high as at very low pressures; but that the difference is upon the other side. At those pressures, therefore, which are most used in machinery, the resistance of friction is vastly less than we have been led to suppose. The fact that the journals were of steel instead of iron does not modify this conclusion. Steel, cast iron, and wrought iron all give very nearly the same figures up to their limits of pressure, when well worn.

The next table exhibits the results of experiments up to still higher pressures, and with other journals and bearings.

TABLE LVI.

COEFFICIENTS OF FRICTION, OF MOTION, AND OF REST.

(*a.*)—CAST-IRON JOURNALS AND STEEL BOXES.

Pressures Per Sq. Inch.	B. W. SPERM.			WEST VIRGINIA.			LARD.			Temperature in all cases less than 115° Fahr. Velocity of rubbing, 150 feet per minute.
	At 150 Feet Per Minute f.	At Starting f'	At Instant of Stopping f''	At 150 Feet Per Minute f.	At Starting f'	At Instant of Stopping f''	At 150 Feet Per Minute f.	At Starting f'	At instant of Stopping f''	
50	.013	.07	.03	.0213	.11	.025	.02	.07	.01	W. B. Sperm Lard.
100	.008	.135	.025	.015	.135	.025	.0137	.11	.0225	Ratio of $\frac{b}{a}$ = 0.75 for 500, 0.77.
250	.005	.14	.04	.009	.14	.026	.0085	.11	.016	
500	.034	.15	.03	.00525	.15	.018	.00525	.10	.016	Ratio of $\frac{b}{a}$ = 0.888 for 1,000, 0.70.
750	.0043	.185	.03	.005	.185	.0147	.0066	.12	.02	
1,000	.009	.18	.03	.010	.18	.027	.0125	.12	.019	
(*b.*)—STEEL JOURNALS AND BRASS BOXES.										
500	.0025						.004			
1,000	.008						.009			

Studying this table, we see that the coefficient rapidly diminishes with increase of pressure until a pressure of over 500 pounds per square inch (35 kilogs. per square centimetre) is attained; the coefficient after passing a pressure of probably 600 to 800 pounds per square inch, (42 or 56 kilogs. per square centimetre) increases, and at 1,000 pounds (70.3 kilogs.) becomes about equal to that obtained at 100 pounds (7 kilogs.). It will be remembered that 500 or 600 pounds (35 or 42 kilogs.) pressure is usually considered to be a limit not to be exceeded in general practice in machine construction.

Nevertheless, it is not uncommon to find as high pressures as 1,000 or even 1,200 pounds (70 or 85 kilogrammes) in the crank-pins of steam-engines. In such cases, however, the pins are almost invariably of steel, and the journals of good bronze —conditions which are less seldom met with elsewhere. There is also, in this case, as wherever a "reciprocating force" acts to move a piece, a condition which permits higher pressures to be successfully worked than can be reached elsewhere. The alternate application and relief of pressure occurring between journal and bearing at each change of direction of the driving force causes a release at such times which permits the oil

to find its way between the rubbing surfaces, and its expulsion is not then fully effected before the succeeding relief of pressure again permits its renewal. A somewhat similar action is consequent upon the rise and fall of a locomotive or of a railway carriage on its springs as it rapidly traverses even a smooth track.

Where, as in the testing-machine, under a fly wheel-shaft, or in other machinery, this relief cannot take place, the limit of pressure is earlier met.

Referring again to the last table, it is seen that between 100 and 750 pounds (7 and 10.5 kilogrammes) the value of the coefficient may be obtained approximately by the expression

$$f = \frac{a}{\sqrt{P}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21).$$

in which a is a constant quantity and P is the pressure in pounds per square inch; for sperm oil $a = 0.080$; for the best crude heavy mineral oil $a = 0.150$, and for lard oil $a = 0.125$.* It will presently be seen that the law is modified by temperature and speed.

240. Friction of Greases.—The following data were given by trials of two excellent kinds of grease, and of sperm oil, compared with them as standard.

TABLE LVII.

COEFFICIENTS OF FRICTION OF GREASES.

STEEL JOURNALS; BRONZE BEARINGS. VELOCITY, 300 FEET (91 METRES) PER MINUTE.

LUBRICANT.	PRESSURE—LBS. PER SQ. INCH. KILOGRAMMES PER SQ. CM.					AV.
	100. 7.	200 14.	300. 21.	400. 28.	500. 35.	
Sperm Oil.....	0.0141	0.0063	0.0049	0.0042	0.0039	0.006
Grease, No. 1.....	0.0249	0.0146	0.0125	0.0105	0.0114	0.0147
" No. 2.....	0.0188	0.0198	0.0160	0.0146	0.0175	0.0170

* These facts and deductions were published originally in a paper prepared in the spring of the year 1878, and read at the St. Louis meeting of the American Association for the Advancement of Science.

Their relative average values in reducing friction stand, therefore: sperm, 100; No. 1, 448; No. 2, 377, which figures would also represent their relative money values if estimated on that basis simply.

The method of variation with pressure already noted, is here again illustrated, although the mathematical expression has a different set of constants, and the variation at this speed is more nearly as the inverse ratio of the cube root of the pressure.

241. Friction of Quiescence.—In Table LVI., Article 239, is presented a set of figures which are both new and important. In the columns headed "At 150 feet per minute" are given the coefficient of friction at the several pressures as given when the rubbing surfaces are in motion at that relative velocity. These are the common and most usually required figures. We have given in the other columns, however, values which are seen at a glance to be immensely greater, and of which the values vary by an entirely different law.

The first set "at starting," are the well-understood coefficients of friction of rest, varying with the pressure and with the nature of the unguent from 0.07 to 0.18. These values have never been determined before in this way, and possess great importance, not simply intrinsically but also as throwing some light upon the effect of motion upon the efficacy of lubrication. It is seen that they increase with the pressure, instead of diminishing as do the coefficients of friction of motion, and that at the highest pressures their values become from ten to forty times the corresponding values of the latter. It is thus seen that in the effort required to move heavy machinery, vastly greater force is demanded to overcome friction at the instant of starting than after motion has once commenced.

The method of variation of the coefficients for rest is seen, by reference to the table, to be such that their numerical values may be approximately estimated for the cases here considered by the formula

$$f' = a' \sqrt[3]{P}, \quad \ldots \ldots \quad (22).$$

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in which $a' = 0.02$ for sperm and heavy mineral oils, and $a' = 0.015$ for lard oil.*

The figures in the columns headed "At instant of stopping" were given while the machine was rapidly coming to a stop, after the driving-belt had been shifted to the loose pulley. They are, as would be expected, intermediate in value between the other figures, and have apparently no practical importance. They may be taken as constant at all pressures.

Even the figures above given are probably higher than those sometimes reached with old journals which have been kept in good order many months or years, and which have worn to that remarkable mirror-like smoothness which is familiar to every experienced mechanic. On the "railroad machine" values have been reached for sperm, and even lard, as low as one-fourth of one per cent., at pressures of less than 500 pounds per square inch, while cylinder-lubricants, applied to bearings heated to the temperature of steam at 100 pounds pressure, have given coefficients as low as one-ninth of one per cent.

242. Friction with Varying Velocity.—It is only recently that it has been found that a serious modification of the value of the coefficient of friction may sometimes be produced by change of velocity. Experiments made by late investigators have shown that, for very low velocities, in the cases studied, the frictional resistance to sliding is comparatively small, that it gradually and somewhat rapidly increases to a maximum as the velocity of sliding augments, and then, at higher velocities diminishes again.

Referring to Table LVIII., on page 272, in which the effects of varying velocities, as well as of coincident variation of pressure and of temperature, are exhibited as given by experiments of the Author, it is readily seen that the changes in value of the coefficient of friction with change of velocity is not great for machinery in which that velocity remains within usual limits, and at the usual temperature of a cool and properly working journal. The effect of change of velocity

* See paper by the Author, in "Proceedings of American Association for Advancement of Science," St. Louis meeting, 1878.

TABLE LVIII.

COEFFICIENTS OF FRICTION—VELOCITY, PRESSURE AND TEMPERATURE VARIABLE.

NEW JOURNAL OF STEEL; BEARINGS OF BRONZE.

Lubricant: Standard Sperm Oil.

SPEED PER MIN.		9 METRES, OR 30 FT.					30 METRES, OR 100 FT.					76 METRES, OR 250 FT.		152 METRES, OR 500 FT.		366 METRES, OR 1,200 FT.		
PRESSURE LBS. PER SQ. IN.		200	150	100	50	4	200	150	100	50	4	200	100	200	100	200	150	100
KILOG. PER SQ. CENT.		98	68	44	22	1.8	98	68	44	22	1.8	98	44	98	44	98	68	44
TEMPERATURE.																		
CENT.	FAHR.																	
66°	150°	.0500	.0500	.0250	.0125	.125	.0140	.0074	.0025	.0037	.0630	.0047	.0028	.0053	.0037	.0060	.0058	.0061
60	140	.0250	.0330	.0110	.0087	.125	.0100	.0050	0025	.0036	.0630	.0047	.0030	.0053	.0037	.0062	.0058	.0070
54	130	.0160	.0200	.0044	0075	.125	.0087	.0041	.0019	.0037	.0630	.0047	.0030	.0053	.0037	.0065	.0062	.0075
49	120	.0110	.0110	.0044	.0075	.125	.0056	.0035	.0019	.0037	.0630	.0047	.0037	.0056	.0037	.0069	.0067	.0080
43	110	.0100	.0033	.0037	.0062	.094	.0044	.0033	.0019	.0037	.0630	.0050	.0044	.0062	.0050	.0075	.0075	.0087
38	100	.0075	.0028	.0031	.0056	.094	.0040	.0033	.0019	.0037	.0630	.0056	.0045	.0065	.0061	0081	.0083	.0094
32	90	.0056	.0025	.0031	.0037	.094	.0040	.0033	.0019	.0037	.0630	.0070	.0052	.0075	.0061	.0100	.0170	.0150

varies, as is here shown, with change of temperature and of pressure.

For cool journals in good condition, lubricated with good sperm oil, and between the limits of 100 and 1,200 feet (30 and 365 metres) per minute, these values may be taken as varying approximately as the fifth root of the speed of rubbing, *i.e.*:

$$f = a\sqrt[5]{V}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (23.)$$

At a constant pressure of, say, 200 pounds (14 kilogs.), we may call $a = 0.0015$.

243. Friction with Varying Pressures, and Temperatures.—We have in Table LIX. exceedingly interesting data, which were obtained by heating the bearing by its own friction to a maximum 170° F. (77° C.), well within that liable to produce alterations of the oil, and noting the friction at successive temperatures while cooling. It should be remembered that these temperature readings can be taken as only approximate.

The figures here given would indicate that the sperm oil, used in this instance and under these conditions, including that of exceptionally low speed, works best at lowest temperatures, and that a heating journal gives rapidly increasing friction and rapidly increasing danger. At usual temperatures—90° to 110° Fahr.—the best pressure seems to have been from 100 to 150 pounds on the square inch (7 to 10.5 kilogs. per square centimetre).

We have seen that at the low speed of 30 feet (9 metres) per minute the coefficient increases rapidly with increase of temperature, and that, at 200 pounds (14 kilogs.) pressure, an increase of 50° F. (10° C.) may increase its value to nearly 10 times the minimum, the rate of increase rapidly rising as pressures are greater.

We now find,* at speeds of 100 feet (30 metres) per min-

* These qualifying conditions were first stated in a paper by the Author, read before the Amer. Inst. Mining Engineers, Oct., 1878. See *Proc. A. I. M. E.*, and *Jour. Franklin Inst.*, November, 1878.

ute, that the friction does not vary between 90° and 150° F. (32° and 66° C.) at pressures below 50 pounds per square inch (3.5 kilogs. per square centimetre); but that it rises nearly 300 per cent. at a pressure of 200 pounds (14 kilogs.), over 100 per cent. at 150 pounds (10.5 kilogs.), and 33 per cent. at 100 pounds (7 kilogs.).

TABLE LIX.

FRICTION AND TEMPERATURE.

STEEL JOURNALS. LUBRICANT, SPERM OIL. VELOCITY, 30 FEET PER MINUTE.

PRESSURE.		TEMPERATURE.		COEFFICIENT OF FRICTION,
Pounds per square inch.	Kilogs. per sq. cm.	Fahr.	Cent.	*f*.
200	14	150°	66°	0.0500
200	14	140	60	0.0250
200	14	130	54	0.0160
200	14	120	49	0.0110
200	14	110	43	0.0100
200	14	100	38	0.0075
200	14	95	35	0.0060
200	14	90	32	0.0056
150	10.5	110	43	0.0035
100	7	110	43	0.0025
50	3.5	110	43	0.0035
4	1.8	110	43	0.0500
200	14	90	26	0.0040
150	10.5	90	26	0.0025
100	7	90	26	0.0025
50	3.5	90	26	0.0035
4	1.8	90	26	0.0400

At speeds exceeding 100 feet (30 metres), per minute, heating the journal within this range of temperature *decreases* the resistance due to friction, rapidly at first; then slowly and gradually a temperature is approached at which increase takes place and progresses at a rapidly accelerating rate. It is seen that this change of law takes place at a temperature of 120° F. (49° C.) and upward; at all higher speeds the decrease continues until temperatures are attained exceeding those usually permitted in machinery, and very commonly not far from 150° F. (66° C.), and sometimes up to 180° F. (82° C.), or

probably even higher. The author found the decrease at 1,200 feet (366 metres), per minute to continue up to 175° F. (79° C.), at which the value, at 200 pounds (14 kilogs.), pressure, was, in the cases determined, 0.0050. The limit of decrease is reached under 100 pounds (7 kilogs.), pressure, at 150° F. (66° C.), when running at this high speed.

At 200 pounds (14 kilogs.) pressure, the *temperature of minimum friction* for conditions here illustrated seems to be, in Fahrenheit degrees, about

$$t = 15 \sqrt[3]{V}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (24).$$

On either side this point on the thermometric scale it may be assumed, for a narrow range, to vary as the temperature departs from that point, directly or inversely, as the case may be, as the temperature. The coefficient of minimum friction is found usually over quite a wide range of temperature.

Again, studying in this most instructive of our tables, the method of variation with pressure at higher temperatures, we find the effect of change of pressure to be much more marked at the higher temperatures at low speeds; and we note, as when studying the effect of variations of friction with change of temperature at a standard pressure as affected by variation of speed, we here find a change of law for the higher speeds.

At a velocity of 1,200 feet (366 metres) per minute, the coefficient remains practically uniform with varying pressure at 150° F. (66° C.), while below that temperature the friction coefficient diminishes with increasing pressure. At velocities of rubbing of 250 to 500 feet (76 to 152 metres) per minute, the temperature of the constant coefficient is about 100°; at 100 feet (30 metres), this peculiar condition is seen at about 120° F. (49° C.), when *extreme* pressures are compared, but the value is seen to be a little over one-half as much at 50 and 150 pounds (3.5 and 10.5 kilogs), and to become a minimum—0.0019—at 100 pounds (7 kilogs.) pressure; a similar behavior is noted at the lowest speed observed—30 feet (9

metres)—at about 125°F. (52° C.), and the same fall to a minimum at the intermediate pressure.

It would seem that at all times there is a tendency to an acceleration of outflow from the journal, with increasing of fluidity due to increasing temperature, which tends to cause an increase of friction, while the effort of capillarity to resist this outflow seems effectively aided by increasing the velocity of rubbing.

A *balance* between these opposite influences is seen to take place in these cases at the slowest speed when the pressure is somewhere below 4 pounds per square inch (1.8 kilogs. per square centimetre); this occurs at a speed of 100 feet (30 metres) per minute at a pressure of 50 pounds (3.5 kilogs.), at 250 feet (76 metres), when the pressure becomes about 150 pounds (10.5 kilogs.) probably; it happens at a speed of 500 feet (152 metres), at somewhere about the same point, and at 1,200 feet (366 metres), per minute the benefit of increased speed is sufficient to produce this balance when the pressure exceeds 200 pounds per square inch (14 kilogs. per square centimetre).

It has become evident that such a series of comparisons as is made are needed in every case in which the real value and the extent and the conditions of application of any single oil or other unguent are to be learned. Such a systematic examination reveals precisely the conditions which the lubricant best meets, and tells with certainty at what pressure and at what speed it does its best work.

Conversely, the speed, the pressure, and other conditions of working being known, a reference to a set of such determinations for various lubricants being made, it is easy to ascertain at once which is best adapted to the work in view.

Thus, having had occasion to determine the value of the friction coefficient of a material having a very high reputation as a "cylinder oil"—*i. e.* an oil for use in the cylinders of steam engines—it was found that its distinguishing peculiarity, as compared with oils not specially adapted for such purpose, was a continually diminishing coefficient quite up to the limits of temperature of locomotive steam pressure.

Any new lubricant should always have its true value and best adaptations thus determined. The Author has presented the figures for a fine steel journal running in good bronze bearings, and lubricated with sperm oil, not simply as an illustration, but principally as representative of the best set of conditions for use as a *standard* in making comparisons of other unguents of less value or less known, or under less favorable conditions.

244. Endurance or Wearing Power of Lubricants.—The difficulties to be encountered in attempts to determine, with even approximate accuracy, the wearing power of lubricating materials, have already been referred to; but only experience can enable one to fully realize the patience and care demanded in the effort to secure reliable data.

Testing a large number of the oils* of commerce for durability on a cast-iron journal, the Author at one time used 32 milligrammes at each application, and noted the *time required to run the journal dry*, with this result:

TABLE LX.

OILS OF COMMERCE, AVERAGE ENDURANCE.

PRESSURE.		RUNNING TIME, MINUTES.			RISE OF TEMP., b.		AVE. COEFFICIENT, f.	HEAT COEFFICIENT $100\frac{a}{b}=c$.	
Lbs. per sq. inch.	Kilogs per sq. mm.	Ave, a.	Min.	Max.	F.	C.		F.	C.
8	56	82	17	411	167°	93°	0.20	50	28
16	112	29	9	97	212	118	0.16	14	8
32	224	10	2	19	228	127	0.12	5	3
48	336	8	1	13	228	127	0.10	4	2

The "heat coefficient" is a valuable datum, as exhibiting the relative increase of temperature per minute during the trial. Its value is sometimes—wrongly, although in some cases nearly correct—taken as a measure of endurance.

Several well known oils ran thus—the speed being 750 ft. (228 metres) per minute.

* This collection included many oils of little value as lubricants.

TABLE LXI.

ENDURANCE OF LUBRICANTS ON CAST IRON.*

NAME.	PRESSURE. Lbs. per sq. inch.	PRESSURE. Kilogs. per sq. cm.	RUNNING TIME. minutes.	RISE OF TEM. Fahr.	RISE OF TEM. Cent.	COEFF. *f.* MEAN.	HEAT COEFF. *c.* Fahr.	HEAT COEFF. *c.* Cent.
Summer Sperm..	8	0.6	111	230°	128°	0.13	48.2	24.5
Summer Sperm..	16	1.1	29	225	125	0.10	12.8	7.1
Summer Sperm..	48	3.3	9	195	108	0.08	4.6	2.5
Lard.....	8	0.6	165	270	150	0.13	61.1	33.9
Lard.....	16	1.1	33	215	149	0.11	15.3	8.5
Lard.....	48	3.3	7	265	135	0.10	2.3	1.3
Olive.....	8	0.6	83	170	94	0.13	48.8	27.1
Olive.....	16	1.1	41	245	136	0.10	16.7	9.3
Olive.....	48	3.3	14	240	135	0.06	5.8	3.2
Cotton Seed.....	8	0.6	107	185	103	0.16	57.8	32.1
Cotton Seed.....	16	1.1	45	275	132	0.12	16.3	9.1
Cotton Seed.....	48	3.3	12	310	173	0.07	3.9	2.2
Cod.....	8	0.6	40	200	111	0.15	20.0	11.1
Cod.....	16	1.1	14	175	97	0.12	8.0	4.4
Cod.....	48	3.3	9	220	122	0.07	4.1	2.3
Crude Mineral (?)	8	0.6	129	105	56	0.10	122.0	67.8
Crude Mineral (?)	16	1.1	97	285	158	0.10	34.0	1.9
Crude Mineral (?)	48	2.3	5	270	150	0.10	1.8	1.3

Comparing a mixture of plumbago and grease with sperm oil, the former was found to have a lower coefficient, to heat up less rapidly and to endure several times as long. It was also indicated that plumbago in very fine flakes was better than in an impalpable powder—a result which was quite unexpected.†

Testing for durability, on a small steel journal, sperm and lard oils gave these results:

TABLE LXII.

ENDURANCE OF SPERM AND LARD OILS.

Durability of one 8-milligramme drop: Feet or metres Run.

POUNDS PER SQ. IN. / KILOGS. PER SQ. CM.	100 / 7		200 / 14		250 / 17.5		275 / 20	
	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.	Feet.	Metres.
Sperm.....	7,204	2,196	7,685	2,343	7,675	2,339	7,521	2,281
Lard.....	6,797	2,072	7,139	2,177	7,090	2.131	7,008	2,136

* See *Polytechnic Review*, March 3, 1877.

† See *American Machinist*, November, 1873, p. 3

Others of the commercial oils found in the market, and largely purchased by consumers who have no means of testing them, endure but for a very small fraction of the time and the distance traveled with sperm and lard, and the author never yet found an oil which equals sperm in this quality.

The "Railroad Machine" has given the following for sperm and lard oils, using a much larger quantity,

ENDURANCE—DISTANCE TRAVELED.

PRESSURE ON JOURNAL.	Lbs. sq. in. 300.	Kilos. sq. cm. 21.	Lbs. sq. in. 500.	Kilos. sq. cm. 35.
	ft.	m.	ft.	m.
Sperm, raw	19,800	6,036	13,500	4,116
Lard, raw..	10,557	3,218	7,515	2,291

The coefficients being,

Sperm,	0.0046	0 0033
Lard,	0.0059	0.0044

The journal was in this case of very soft steel, 3¼ inches (8.2 cm.) in diameter and 7 inches (17.8 cm.) long, and was driven at a speed corresponding to 20 miles (32 kilometres) an hour on the track.

In the attempt to make use of such determinations of the endurance of lubricants in daily practice, the investigator meets with a serious difficulty, which has no relation to the character of the material used. It is an important fact, and one which should be constantly borne in mind, that the maximum wearing power of a lubricant, as we have here defined and determined it, has no necessarily definite relation to the quantity which will be actually used, or even required, when working under other conditions.

Usually the same amount will be used, whether it be of great or little wearing power, the amount being generally determined by the method of feeding more than by its intrinsic character. Other things being equal, the more viscous will

feed more slowly, and will, therefore, be apparently of higher wearing power than the more fluid lubricant; a grease will last longer than an oil; the method of applying the lubricant to the journal will determine whether it is economically or wastefully used. These last are vastly more important facts than they are generally supposed to be; regular trains on railroads have been known to use *nine times as much* * grease as an experimental train on which the most rigid economy was exercised.

It thus becomes evident that the proper method of procedure is to first determine the value of the lubricant by a series of careful tests at the pressures, velocities, and temperatures, and with the kind of rubbing surfaces proposed to be used, *then* to find and adopt that method of feeding which will insure maximum economy. As a rule, however, determinations of endurance are of comparatively little value in every-day practice; because their use is rarely, and seldom can be, regulated by their endurance; the same amount would generally be used and the same quantity wasted, whether the wearing quality be high or low. The real value of a lubricant is, therefore, generally measured by its power of reducing friction, as already remarked.

The following are the details of a trial reported at the Brooklyn Navy Yard, in which a less certain but less troublesome method was adopted:

The oil was measured by dropping. The same quantity, five (5) drops, was used in all the tests.

When a seeming discrepancy appeared, or doubt arose regarding any result, the experiment was repeated until satisfaction was obtained.

The driving power came from the Navy Yard engine, and the speed of the testing machine varied with the work done by the engine. Owing to this cause it was not claimed that the results were absolutely correct. The average speed was, however, taken, which so nearly approximates uniformity, that the data may be considered correct for all practical pur-

* *Railroad Gazette*, Sept. 20, 1878.

poses of comparison. Two series of tests were made, one of three (3) minutes runs, and another of one (1) minute each.

Columns *b* and *e* give the increase of heat in degrees (Fahrenheit) of the journal, starting from a nearly constant temperature of 78° or 80°. The unit of comparison is the

TABLE LXIII.

OILS.	ONE MINUTE RUNS.				THREE MINUTE RUNS.				
	Revolutions.	Increase of heat in units of degrees Fahrenheit.	Coefficient *c*.	Comparative efficiency, sperm being 100.	Total Revolutions.	Per Minute.	Increase of heat in units of degrees Fahrenheit.	Coefficient *f*.	Comparative efficiency, sperm being 100.
	a	*b*	$\frac{a}{b} = c$	*h*	*d*	*a'*	*e*	$\frac{d}{e} = f$	*h'*
Sperm.....	1,812	43.5	41.6	100	5,506	1835.3	82	67.1	100
Prime Lard....	1,790	46	38.8	93.2	5,741	1913.6	90	63.8	95.1
Lard No. 1 ...	1,883	50	37.6	90.5	5,428	1807	90	60.3	89.8
Lard No. 2 ...	1,810	50	36.2	87.02	5,500	1833	96	57.3	85.4

number of revolutions obtained for each degree of increase in temperature, and is obtained, in the minute runs, by dividing column *a* by column *b*, which gives the coefficient column *c*; $\left(\frac{a}{b} = c\right)$ and in three (3) minutes runs by dividing column *d* by *e*, giving the coefficient in column *f*; $\left(\frac{d}{e} = f\right)$.

Columns *h* and *h'* compare the efficiency on the basis of sperm being 100.

It need not be repeated here that the ratio of heat developed to revolutions made or distance traversed has no necessary and definite relation to the real power of endurance of the oil.

245. Commercial Value of Lubricants.—The *real* value of a lubricant to the user is a somewhat difficult quantity to determine, since it really depends, not upon the relative friction-reducing power and endurance, as usually

assumed, but upon the value of the power saved by its use. This value varies in every case, and is affected by every variation of working conditions.

The *market* value is determined, as in all commercial operations, by that law of supply and demand which usually, if sufficient time is allowed for its operation, brings prices into a correct relative order, but not necessarily into a true proportion of values. It is generally the fact that "the best is the cheapest" to the consumer, and this rule is probably almost always applicable in the purchase and use of lubricants. It is frequently the fact that the consumer can better afford to use the highest priced article than to take those of lower value as a gift.

The following table shows a usual order of commercial value of the principal fluid oils:

1. Sperm Oil.
2. { Seal Oil, Olive Oil, Lard Oil. } These may change places at times.
5. Rape seed Oil.
6. Other seed Oils. { Cotton seed, Linseed.
7. Castor Oil.
8. Fish Oils, { Cod, Menhaden.
9. Whale.
10. Rosin Oil.
11. Mineral Oils.

An approximate value by which to compare the oils can be calculated, based on the assumption that they will have a money value proportionate to their durability and to the *inverse* ratio of the value of the coefficient of friction. Thus; suppose two oils to run, one 10 minutes and the other 5, under a pressure of 100 pounds per square inch, and both at the same speed, and suppose them to give, on test for friction, the coefficients 0.10 and 0.06 respectively.

Their relative values might be taken at $\frac{10}{10} = 1$ and $\frac{5}{6} = 0.833$. If the first is worth one dollar, the second should be worth 83⅓ cents.

In many cases, however, about the same quantity would be applied by the oiler, whatever oil might be used, and their values to the consumer would be in the inverse proportion of the values of their coefficients of friction, *i. e.*, as 6 in the above case is to 10, thus making the value of the second $1.66⅔, and showing that it would be better to use the latter at anything less than this price than the first at $1.

Engineers have been accustomed to use these methods of comparison in reporting upon the values of lubricants sent in for test, simply because they are generally considered to be correct by dealers and users, and because there has been no better method suggested of assigning an approximate figure for market price. The real difference in values of any lubricants to any user may, nevertheless, be determined in any given case when the cost of power is exactly known, and when the quantity of the several unguents required to do the same work has been found, and their several coefficients of friction given. The difference in actual value to the user when any two unguents are compared, is measured by the cost of the difference in the amount of power expended in driving the machinery when lubricated first with the one and then with the other of the two materials. As power is usually much more expensive when developed in small than when demanded in large amounts, the economy to be secured by adopting a good lubricant is the greater as the magnitude of the work is less. In large mills, and wherever work is done on a very large scale, the cost per horse power and per annum may be taken often at about $50 a year, while for small powers this figure is doubled or even trebled and quadrupled. Every reduction of power to the extent of one horse power by the introduction of an improved material or system of lubrication thus effects a saving of $50 a year and upward; the difference between this amount and the extra cost of the new kind of lubricant represents the annual profit made by the change. Should it happen, as is sometimes the fact, that the better unguent is also the cheaper, an additional profit is made which is measured by that saving in cost.

In an ordinary small mill, or in a machine shop in which 100

horse power is used, a change in lubricant will often effect an average saving of 5 horse power, and a consequent economy of, probably, $500 a year. The total amount of oil used in such a case might exceed 100 gallons, but may sometimes be as little as 40 gallons. The consumer could, in such a case, better afford to pay $5, or perhaps even over $10 per gallon, for the good oil, than accept the less valuable lubricant as a gift.

246. The best Lubricants are in general the following, for usual conditions met with in practice:

Under low temperatures—as in rock-drills driven by compressed air—*light petroleums.*

Under very great pressures with slow speed—*graphite, soapstone*, and other solid lubricants.

Under heavy pressure with slow speed, the above, and lard, tallow, and other greases.

Heavy pressures and high speed—sperm oil, castor oil.

Light pressures and high speed—sperm, *refined petroleum*, olive, rape, cotton seed.

Ordinary machinery—lard oil, tallow oil, heavy mineral oils and the heavy vegetable oils.

Steam cylinders—heavy mineral oils, lard, tallow.

Watches and other delicate mechanism—clarified sperm, neat's-foot, porpoise, and olive oils.

For mixture with mineral oils, sperm is best; lard is much used.

CHAPTER VI.

MISCELLANEOUS MATERIALS:

Leather; Belting; Paper; India Rubber; Gutta Percha; Cordage.

247. Leather; Belts.—One of the principal uses of leather in engineering is in its application in the form of belting, for driving machinery. The best quality is well tanned ox-hide, cut from the back of the animal, and very exactly trimmed, to form perfectly straight strips of uniform thickness. These strips, which are from 4 to 6 feet (1.2 to 1.8 m.) long, and usually about three-sixteenths of an inch (0.48 cm.) in thickness, are scarped, spliced, and cemented end to end, to make any desired length of belt.

"Single" belts are those made of a single thickness of leather. Extra strong belts are made by cementing or riveting together two thicknesses of leather to form a "double belt." Under light loads the single belt has the greatest adhesion; but under heavy loads the double belt is fully as efficient. Double belts are sometimes made 6 feet (1.2 metres) wide, and 100 to 150 feet (30 to 45 metres) long.

The inside of the hide is called the "flesh side;" the outside the "grain side." The belt wears best when placed with the flesh side next the pulley. Some engineers, however, advise the reverse position, as the belt is less liable to slip.

The weight of hard, well-tanned belt leather is about that of water, 62½ pounds per cubic foot (1,000 kilogrammes per cubic metre), and may be taken, at an average, as about 0.85 pounds per square foot (4 kilogrammes per square metre).

The tenacity of belt leather of good quality is about 650 pounds per inch in width (115 kilogrammes per cm. wide), one half that amount when spliced and riveted, and one

third when laced. The safe working tension is given by some engineers as 50 pounds per inch of breadth (9 kilogrammes per centimetre).

Belt lacings are strips of sheepskin, about a half inch (1.27 cm.) wide, and a yard (0.9 metre) or more in length. In joining belt ends, the belt is pulled taut, and, if heavy, stretched and held by "belt-clamps," cut so that the ends just meet, and a single, or double, or even a triple row of holes, according to its size and tightness, punched to receive the lacing. The holes should be exactly in line. The lacing is then passed through these holes, backward and forward, joining the two ends evenly and strongly. Small, strong tempered steel hooks are often used instead of lacing.

Calfskin, well tanned, stretched wet, makes good lacings.

The firmest and best method of uniting leather belts is to scarf the ends so as to lap a distance of not less than ten, nor usually more than twenty, times, their thickness, adjusting the length of the belt carefully by setting up well with "belt-clamps," and then cementing the parts well, finally securing the lap by copper rivets. The next best method is probably that of connecting the ends by steel hooks, and the least effective, but probably most usual, way is by lacing.

The stress allowed on a single belt may be taken at 300 pounds per inch of width (55 kilogrammes per cm.) Mŏrin allows 284 pounds per square inch (20 kilogrammes per square cm.), and Claudel 355 pounds (25 kilogrammes). Rankine takes 285 pounds per square inch of section (20 kilogrammes per square cm.), and assumes the usual thickness as 0.16 inch (0.4 cm.).

In very fast-running belts, the tension given in setting up is sometimes increased by centrifugal action to such an extent that it should be allowed for in calculating the width required. This "centrifrugal tension" is thus measured:

A belt of the section s, density d, and running at the velocity v, in passing from one side to the other of the pulley exhibits energy, in one direction, measured each second by

$$E = sdv \times \frac{v^2}{2g}; \quad . \quad . \quad . \quad . \quad . \quad (1).$$

this energy is first destroyed and then is reproduced in the opposite direction on the other side of the pulley. The total energy is thus:

$$2E = sd\,\frac{v^2}{g}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

The effort demanded to produce this reversal is $\frac{2E}{v}$,

or,

$$F = \frac{2E}{v} = \frac{sdv^2}{g}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3).$$

The required section of belt now, instead of $s = \frac{T}{t}$, in which T is the total tension, and t is the safe working tension per square unit of section of the material as above, becomes,

$$s = \frac{T}{t - \frac{dv^2}{g}}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4).$$

248. The Friction of leather belts is relied upon to prevent slipping. This friction is at each point of contact proportional to the pressure there existing, and the total resistances to slipping is obtained by summing the resistances throughout the arc of contact.

The pressure at each point is equal to the tension at that point, as is seen when it is considered that it is the same as would exist were that tension uniform, and were there no friction throughout the arc of contact. But this tension is actually variable in consequence of the existence of friction, and we have, as shown by Rankine,

$$dR = fTd\theta, = dT, \quad . \quad . \quad . \quad . \quad . \quad . \quad (5).$$

when $R = T_1 - T_2$, the working stress, *i. e.*, the difference of tension at the extremities of the arc, $f =$ the coefficient of friction, and $\theta =$ the arc of contact; and

$$\int_{T_2}^{T_1} \frac{dT}{T} = f\int d\theta = \log_e \frac{T_1}{T_2} = f\theta \quad . \quad . \quad . \quad (6).$$

$$R = T_1 - T_2 = T_1(1 - e^{-f\theta}) = T_2(e^{f\theta} - 1), \quad . \quad (7).$$

since

$$T_1 = T_2 e^{f\theta}; \quad T_2 = T_1 e^{-f\theta}; \quad T_1 + T_2 = T_2(e^{f\theta} + 1).$$

The mean tension is $\frac{T_1 + T_2}{2}$, and

$$\frac{T_1 + T_2}{2} \div R = \frac{e^{f\theta} + 1}{e^{f\theta} - 1} \quad . \quad . \quad . \quad . \quad (8).$$

Since $\theta = 2\pi n$, when n = arc of contact in "turns," $e^{f\theta} = 10^{2.7288 fn}$. When this arc is expressed in degrees,

$$R = T_1(1 - 10^{-0.00320\theta}).$$

The following are values* of the factors:

When $\theta = \pi$ and $n = \frac{1}{2}$, as where the pulleys are of equal size:

TABLE LXIV.

TENSION AND FRICTION OF BELTS.

$f =$	0.15	0.25	0.42
$2.7288 f =$	0.41	0.68	1.15
$\frac{T_1}{T_2} =$	1.60	2.20	3.76
$\frac{T_1}{R} =$	2.66	1.84	1.36
$\frac{T_1 + T_2}{2R} =$	2.16	1.34	0.86

In common practice, it is now usual to take $f = 0.22$, or $f = 0.25$; $T_2 = \frac{1}{2} T_1$, $= R$; $= \frac{T_1 + T_2}{2R} = 1.5$; $R = \frac{1}{3}(T_1 + T_2) = 150$ lbs. per inch (28 kilogrammes per centimetre) of width of belt; but one-half this stress is often observed. An old millwright's rule allows one horse-power for each inch in width running 1,100 feet per minute, *i. e.*,

* Rankine, Machinery and Millwork, § 310.

$HP = \frac{bv}{1100}$; (2.54 centimetres width running 335 metres per minute. Belts are often driven without slip, to nearly double this power.

Nagle gives the following:

For laced belts—$HP = ctvw\,(0.55 - 0.00002157tv^2)$ (9).
For riveted belts—$HP = ctvw\,(1 - 0.00002157tv^2)$ (10).
when

$c = 1 - 10^{-0.000958f\theta}$;
θ = arc of contact, degrees;
w = width of belt, inches.
t = thickness;
v = velocity, feet per second.

Morin gives the following as maximum coefficients of friction of belts:

TABLE LXV.

FRICTION OF BELTS.

	f.
Common cases, iron pulleys	0.28
Wet belts, " "	0.38
Common belts, wooden pulleys	0.47
New " " "	0.50

Where the arc of contact varies, the value of $\frac{T_1}{T_2}$ may be altered thus ($f = 0.28$):

n =	0.2	0.3	0.4	0.5	0.6	0.8	1.0
$\frac{T_1}{T_2}$ =	1.4	1.7	2.0	2.4	2.9	4.0	5.8

Raw Hide, or untanned leather, when perfectly sound, is much stronger than tanned leather, and is much used for some parts of textile machinery connections, in looms, for ship's tiller-ropes, etc. It is cut from the raw skin and dried in the sun. Its strength may be taken as one-half greater than that of leather; its resistance to violent impact is very great.

The *Cement* used for belts may be made by melting together:* 1 part shellac; 2 parts pitch; 2 parts linseed oil; 4 parts India-rubber; 16 parts gutta percha, until thoroughly incorporated. It is applied warm, in a thin coating, very quickly, and the two parts of the belt are promptly and firmly clamped together and left until completely set.

Leather is used for the packing of pumps, and often for their valves.

249. Paper is principally used by the engineer in the drawing-room; but it is occasionally applied in the making of belts, of packing and of other needed articles.

Drawing paper for nice work is made of linen rags reduced to a pulp, and formed into thin sheets having a smooth, peculiarly varied surface, which takes ink and colors well, bears erasures, and is strong and durable. The finished drawings are sometimes coated with a solution of shellac in alcohol (1 part shellac to from 4 to 8 of alcohol), which discolors the sheet, but which enables the draughtsman to wash it when soiled, and prevents that rapid soiling which always occurs when working drawings are handled.

Rough drawings are made on cotton paper of a cheap grade, which comes in long rolls of considerable width.

Shop drawings are usually copies on tracing cloth, or photographically prepared "blue prints," made by using the tracing as a negative, and are mounted on a board to avoid injury by rolling or bending.

The principal sizes of drawing paper are:

Medium	18 x 22 inches.	Columbia	23x33¾ inches.
Royal	19 x 24 "	Atlas	26x33 "
Imperial	21½x29 "	Theorem	28x34 "
Elephant	22½x27½ "	Double Elephant	26x40 "

Of tracing paper we have:

Double Crown	20x30 inches.	Grand Royal	18x24 inches.
Double D Crown	30x40 "	Grand Aigle	27x40 "
Double D D Crown	40x60 "		

* Molesworth.

Tracing cloth comes in rolls of various widths, as does vellum writing paper.

Blotting paper is a thick cotton paper, perfectly free from size or greasy matters.

Lithographic paper is made by coating printing paper with a composition of one part alum, two of gum arabic, and six of starch, dissolved in warm water, and laid on hot with a brush. Tracing paper is made by washing printing paper with a mixture of either Canada balsam and oil of turpentine, or nut oil and turpentine, and thoroughly drying before using it.

Copying ("manifold") paper is writing paper coated with lard and blacklead.

Paper of considerable thickness is known as *pasteboard*, and is extensively used for making boxes to contain light materials.

Paper Belts are sometimes used. They consist of a very hard pressed paper, have great strength and considerable durability, but a low coefficient of friction, and are very stiff and unmanageable. The same material makes the exceedingly light and strong boats used for racing purposes. They are formed and compressed in moulds, and are therefore properly "*papier maché*."

Calender Rolls are made of paper formed and compacted by the hydraulic press. This compacted paper becomes as close in texture as hard wood, very strong, with a very fine, smooth surface, and works like a soft metal.

250. **India Rubber and Gutta Percha** are used in special forms by the engineer; in bands for belting, in sheets for packing, and, to a limited extent, for various minor purposes.

India-rubber, or caoutchouc, is the dried juice or sap of several tropical trees or shrubs. The best, the "Para gum," is obtained from the *Hevea Braziliensis*, one of the Euphorbiaceæ, Ceara rubber from the *Manihot glaziovii*, and Pernambuco gum from the *Hancornia speciosa*. This gum is also obtained from the East Indies, Africa, and Central America.

Pure rubber, if of good quality, is dry, tough, strong, and

enormously elastic. It dissolves freely in benzole, chloroform, carbon disulphide, and the essential oils; contact with oil or grease rapidly destroys it.

All the rubber used by the engineer is "vulcanized" by heating it and incorporating with it 20 to 30 per cent. of sulphur; it then becomes less readily softened by heat or hardened by cold, and makes very durable water-proof articles of many kinds, all of which are made of woven fabrics smeared with the vulcanized rubber. When the proportion of sulphur reaches 30 or 40 per cent., various grades of "ebonite" are produced—a hard, jet black, moderately elastic substance, used by the engineer for making rulers, scales, "triangles," and curves, and in the arts generally, for a great variety of purposes.

India-rubber Belts are made by weaving cotton canvas of the required length and width, and coating it with vulcanized rubber. These belts are made two, three, or four-ply, as they are required to do work demanding the strength of two, three, or four thicknesses. These belts are considerably stronger than leather belts, are usually truer and run more smoothly, and are perfectly impervious to water; they have a higher coefficient of friction, but, if overloaded, are apt to be rapidly and seriously injured by slipping.

India-rubber Valves are largely employed in hydraulic machines. They should be made of well vulcanized rubber, uniform in thickness, cut precisely or moulded exactly to size and shape, and should have just sufficient thickness to safely sustain the pressure thrown on them. In many cases they outlast metal valves.

Gutta Percha is the dried and hardened sap from the bark of trees of the order *Sapotaceæ*, found plentifully in the Malay Peninsula. When pure it is grayish white, becoming brown and yellow with exposure or from the presence of impurities. It is as hard as the softer woods, and can be easily moulded or rolled into sheets having considerable toughness and without elasticity, resembling in density and texture hard leather, having a specific gravity of 0.98 to 1.00. In solubility it resembles rubber, as well as in nearly all other

properties except elasticity. It is an excellent insulator, and is extensively used in telegraphic engineering. It is also used for belting, the same proportions being adopted as with leather.

251. Cordage is usually made of hemp, flax, and cotton, and sometimes of leather, rawhide, and often of wire.

Small cordage is known as *rope;* it is usually composed of three or four strands of "yarns," laid up with a right-hand twist, the strands being laid up with a left-hand twist. *Hawsers* are made up with three right-handed strands, and *cables* with three hawsers laid up left-handed. *Shrouds* are made up with a central core, surrounded by four strands.

Tarred Ropes are less subject to injury by the weather than white cordage, but have one fourth less strength. Cordage takes up from 20 to 30 per cent. of its weight in tar. The larger the cordage the less its strength per unit of section; this loss amounts to nearly 50 per cent. in large cables. Three-strand cordage is ten or fifteen per cent. stronger than four-strand, if rope laid; ten per cent. weaker in hawsers and cables.

The working or maximum proof strength of cordage may be calculated by multiplying the square of the girth in inches by 200 to 300 pounds, or in centimetres by 14 or 22 kilogrammes.

White 2-inch (5 centimetres) hemp rope should carry about 5,000 pounds (2,275 kilogrammes), or nearly one ton weight per pound weight per fathom (say 1,200 kilogrammes per kilogramme weight per metre). The U. S. navy test allows 4,200 pounds on a 1¾-inch white hemp rope, or 1,700 pounds per square inch (1,195 kilogrammes per square centimetre). Manilla rope has about two-thirds the strength of good Russian (Riga) hemp.

The method of connection of ropes is usually by making knots; although permanent union is effected by a "splice," in which the two ends are overlaid for a considerable distance, and their strands mutually interwoven, making a connection as strong as the body of the rope.

Knots cannot well be verbally described; but the following

engravings, selected from Molesworth, represent the principal knots used by the engineer and the seaman. In these illustrations, *W* indicates the direction of the weight, *P* that of the pull.

Fig. 62 is the "half hitch," used to secure the end of a line to any object during a steady pull; Fig. 63 is a "timber hitch," employed for the same purpose, when greater security or a more permanent hold is desired. Fig. 64 exhibits the two hitches used together, the timber hitch backing the half hitch; this arrangement is used at sea in towing spars. With the "clove hitch," Fig. 65, the stick is held in position by a pull on each side; the "rolling hitch, Fig. 66, is a still tighter knot than the timber hitch, as it rolls the lines over, and binds itself as soon as the pull is given.

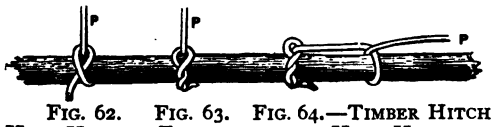

FIG. 62. HALF HITCH. FIG. 63. TIMBER HITCH. FIG. 64.—TIMBER HITCH AND HALF HITCH.

FIG. 65.—CLOVE HITCH. FIG. 66.—ROLLING HITCH. FIG. 67.—REEF KNOT.

The "square knot," or "reef knot," Fig. 67, is the simplest and best knot for uniting rope-ends; the "sheet bend,"

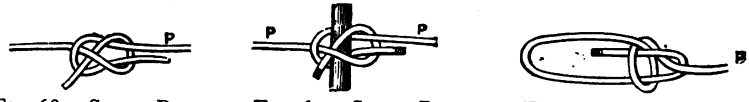

FIG. 68.—SHEET BEND. FIG. 69.—SHEET BEND WITH TOGGLE. FIG. 70.—BOWLINE.

Fig. 68, is somewhat similar; the "sheet bend and toggle," Fig. 69, is easily unloosed, and the "bowline," Fig. 70, forms a loop which can be thrown, lasso-like, over a post, to which it is proposed to make fast.

Fig. 71 shows the method of putting a "stopper" on a rope or cable, for the purpose of holding it in place while shifting the end, or while fleeting it at a winch. The "black-

FIG. 71.—STOPPER ON A ROPE.

wall hitch, the "fisherman's bend," the "round turn and half hitch," Figs. 72, 73 and 74, show how a rope may be made

FIG. 72.—BLACKWALL HITCH.

FIG. 73.—FISHERMAN'S BEND.

FIG. 74.—ROUND TURN AND HALF HITCH.

fast to a hook, or to a link or deadeye, the lashing shown at A on the last two make the line secure.

A "*sling*," or "strop," Fig. 75, which may be either a rope or a chain, has many uses; it is seen in Fig. 76, as used in raising a stone or other heavy mass; in Fig. 77, as used to give a hold for the hook of the tackle; and, in Fig. 78, is illustrated the attachment of stop and "guy ropes" to the head of a derrick.

FIG. 75.—A STROP OR SLING.

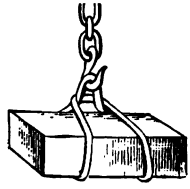

FIG. 76.—SLINGING A CASE.

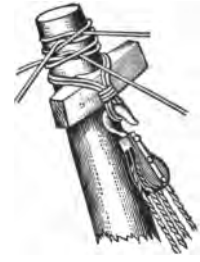

FIG. 78.—HEAD OF A DERRICK.

STROP ON A ROPE TO HOOK A BLOCK TO.

FIG. 77.

APPENDIX.

CONVERSION TABLES.

BRITISH OR UNITED STATES, AND METRIC.

BIRNIE.

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TABLES.

CONVERSION OF METRIC INTO BRITISH OR UNITED STATES MEASURES, AND *VICE VERSA*.*

MEASURES OF LENGTH, SQUARES, AND CUBIC MEASURES.—(TABLES A, B, AND C.)†

SINCE 1868 the U. S. Coast Survey Office has used a value for the metre equal to 39.370432 inches, as determined by an extensive series of comparisons, the results of which are published in a volume entitled *Comparisons of the Standard of Lengths of England, France, Belgium, Prussia, Russia, India, and Australia, made at the Ordnance Survey Office, Southampton*, 1866.

The metre is standard at 0° Cent. (32° Fahr.), and the yard at 62° F. (16° .666 Cent.), and the value above given is that of the metre in inches of the standard yard.

Tables A, B, and C, etc., give the value of each denomination, from 1 to 9 inclusive. They can be applied to all numbers, by decimal multiplication and division, as, for example:

Convert 760 millimetres into inches—Table A:

	INCHES.
700^{mm}	= 27.5593
60 "	= 2.36223
760^{mm}	= 29.922

* Abstract, by permission, from tables prepared by Lieutenant Rogers Birnie, Ordnance Corps, U. S. A. *Ordnance Notes*, No. 192. Published for the use of the U. S. Army by order of Brig. Gen. S. V. Benet, Chief of Ordnance.

† Germany, Belgium, Italy, Spain, Portugal, Holland, Greece, and France, have adopted the metric system and use it generally, while in the United States its use was legalized by Congress in 1866, but is not common.

WEIGHTS.—(TABLE D.)

The Standard Troy pound of the United States, at Philadelphia, is an exact copy of the Imperial Troy pound of Great Britain, obtained in 1827. Elaborate comparisons, since 1855, of this Troy pound, weighing 5,760 grains, and of the commercial or avoirdupois pound of 7,000 grains, derived from the former, with copies of similar weights from the standard pound of Great Britain, have shown that there is less than $\frac{1}{1000}$ of a grain difference between the money standards (Troy weights) of the two countries.* The British *standard pound avoirdupois* is the weight, in the latitude of London, of a certain piece of platinum kept in the Exchequer office.†

In the *Philosophical Transactions for* 1856, page 893 *et seq.*, is published Prof. W. H. Miller's determination of the weight of the kilogramme, equal to 15432.34874 grains, which is accepted as authoritative. This value was used in the preparation of Table D.

PRESSURE OF AN ATMOSPHERE.—(TABLE E.)

The value of the *unit atmosphere* (abbreviated, atmo.) which has been adopted in the metric system and used by Regnault in his investigations to determine the relations between the temperature and pressure of gases, is the pressure of 760 millimetres (29.922 inches) of the mercurial column at 0° Cent. (32° Fahr.) at Paris; which amounts, in that latitude, to 1.0333 kilogrammes on the square centimetre, or 14.6967 pounds on the square inch. In consulting this table it is therefore necessary to remember that it deals with an arbitrary *unit atmosphere.*

The *Encyclopædia Britannica*, Vol. III., page 28, 9th ed., gives us *an atmosphere*, in the English system, the pressure due to 29.905 inches of the mercurial column at 32° Fahr. at London, which atmosphere thus becomes 0.99968 of that of the metrical system. Under this pressure (29.905) water boils at 212° Fahr.

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* Prof. J. Hilgard, in *App.* 22, *U. S. Coast Survey Report for* 1876.

† Rankine's *Applied Mechanics*, 9th ed., page 18.

Rankine assumes as the value of an English *atmosphere* the pressure due to 29.922 inches, which, in the latitude of London, corresponds to a pressure of 14.704 pounds per square inch of the mercurial column at 32° Fahr. This, it will be observed, is the *height* used in the metrical system, which is thus indicated as the universal standard.

There are two ways of taking such a standard. 1st. If the *absolute pressure at Paris*, due to 760 millimetres of the mercurial column at 0° Cent. be assumed, then if we would have the same absolute pressure, in taking readings of the barometer for *pressures* in a different latitude, allowance must be made for a difference of height of the mercurial column, corresponding to the difference between the latitude of the place of observation and that of Paris.

The height of the mercurial column at 0° Cent., giving a pressure equivalent to that of *this* metrical atmosphere, can be computed in centimetres by the following expression:

$$76 \times \frac{(1 + .00531 \sin^2 48° 50')}{1 + .00531 \sin^2 l.}$$

for any latitude l.* (48° 50′ being the latitude of Paris.)

Thus we have for New York city, taking $l = 40° 42' 43''$, a value for the expression, of 76.06314 centimetres = 29.946 inches, which height of the mercurial column at 32° Fahr. at New York city would indicate a pressure equivalent to the metrical atmosphere *of constant pressure*.

2d. On the other hand, assuming the universal standard to be the pressure due to 29.922 inches of the mercurial column at 32° Fahr., then the absolute pressure of *this unit atmosphere* at New York would equal but 14.686 pounds on the square inch, which is 0.999272 of the metrical atmosphere *at Paris*. It may be added that 29.922 inches of the mercurial column at 32° Fahr. corresponds to 30 inches at 57″.8 Fahr.; the reduction to 32° for this reading being — 0.078 of an inch for an observed reading of the attached thermometer of 57°.8 Fahr.

* *Enc. Brit.*, p. 556, Vol. xi.

BENDING-STRESS PER UNIT OF LENGTH.—(TABLE F.)

In the case of a uniformly distributed load, or of a pressure tending to bend a structure, this table enables us to pass from "kilogrammes to the centimetre" to "pounds to the inch," of length, etc., and *vice versa.**

STRESS PER UNIT OF SQUARE AND CUBIC MEASURES.—(TABLES G AND H.)

The first of these tables finds its application in the conversion of expressions giving the tensile strength of materials, wherein we change the metric expression in "kilogrammes to the square millimetre" into "pounds to the square inch," otherwise stated simply as "—— pounds tensile strength." The two tables apply to the conversion of values of forces of compression; the word *stress* being used to indicate a force either of extension or compression.

UNITS OF WORK OR ENERGY.—(TABLE I.)

This table gives the equivalent values of "kilogrammetres" in "foot-pounds," and "tonne-metres" (sometimes written *dynamodes*) in "foot-tons." It will be used in the translation of quantities of work or energy.

THERMOMETERS.—(TABLE J.)

This table presents a tabulated solution of the formula

$$F.^\circ = \frac{C.^\circ \times 9}{5} + 32 = \frac{R.^\circ \times 9}{4} + 32;$$

by decimal multiplication and division it can be applied to all numbers. In passing from either Centigrade or Réaumur to Fahrenheit, we first take out the tabular numbers and then add 32; in the reverse operation we first subtract 32 from the Fahrenheit degrees, to be converted into Centigrade or

* In other words, the *bending moment* is here transferred from one system to the other.

Réaumur, and then take out the tabular numbers corresponding to this remainder, as, for example: Convert 4°.1 Cent. into Fahr.°; from the table we have

$$\begin{aligned} 4°.\ \text{C.} &= 7°.2\ \text{F.} \\ .1\ \text{“} &= .18\ \text{“} \\ \hline 4°.1\text{C.} &= 7°.4\ \text{F.} + 32° = 39°.4\ \text{F.} \end{aligned}$$

or conversely, to convert 62° Fahr. into Cent.°: 62° − 32° = 30°, and from the table we have, 30 = 16.7; hence 62° Fahr. = 16°.7 Cent.*

UNITS OF HEAT.—(TABLE K.)

The thermal unit, centigrade, is the amount of heat required to raise the unit mass of water from 0 to 1° Cent.

This table expresses the relation between the amount of heat required to raise *one kilogramme* (2.2046 pounds) of water from 0 to 1° Cent. (1°.8 Fahr.), and the amount of heat required to raise *one pound* of water 1° Fahr. (from 32° to 33° Fahr.). The mechanical equivalents of the “unit of heat” in the two systems bear a like relation to each other. This mechanical equivalent, in the English system, is the number of foot-pounds of mechanical energy which must be expended in order to raise the temperature of one pound of water one degree. For Fahrenheit's degree that quantity (Joule's equivalent) is 772 foot-pounds; for the centigrade degree $\frac{9}{5}$ of 772 = 1389.6 foot-pounds. If we replace the pound by a kilogramme (2.2046 + pounds), that quantity becomes for the centigrade degree 2.2046 + of $\frac{9}{5}$ of 772 = 3063.54 foot-pounds, which is the mechanical equivalent of the metrical unit of heat, and is equal to 423.55 kilogrammetres.

CONVERSION OF BAROMETRIC READINGS.

With barometers read by the metric scale, to change to the corresponding reading in inches, we have only to change the number of millimetres, given by the metric scale, into

* A later table gives direct conversions.

inches, for which use Table A; for example, a reading of 762 millimetres is given:

$700^{mm} = 27.5593$ inches.
60 " $= 2.3622$ "
2 " $= .0787$ "
$762^{mm} = 30.0000$ inches, which is the reading in inches.

COEFFICIENT OF ELASTICITY FOR LONGITUDINAL STRESS.

This in metrical tables is usually expressed in terms of kilogrammes per square millimetre; to reduce to our usual expression, which (for the weight modulus) is in terms of pounds per square inch, Table G will be used; and we have only to take from that table the number of "pounds per square inch," corresponding to the number expressing the metrical coefficient of elasticity; as, for example, the coefficiency of elasticity (metrical) of a certain specimen of cast-iron is expressed by the number 15,000; from Table G we have:

10,000 kilogrammes to the mm—c = 14,223,087.6 pounds to the sq. inch.
5,000 " " " " " = 7,111,539.3 " " " " "
15,000 = 21,334,618.

which expresses the corresponding coefficient of elasticity for this piece of metal in our own system.

A summary of all the unit values used, with their logarithms, precedes the tables.

METRIC TABLES.

THE METRIC SYSTEM is founded on the metre as the unit of length, and has four other leading units, all connected with and dependent upon it:

(1.) The METRE, the unit of measures of length;

(2.) The ARE, the unit of measures of surface, and the square of ten metres;

(3.) The LITRE, the unit of measures of capacity, and the cube of a tenth part of the metre;

(4.) The STERE, the unit of measures of solidity, having the capacity of a cubic metre;

(5.) The GRAMME, the unit of measures of weight, and the weight of that quantity of distilled water, at its maximum density, which fills the cube of the hundredth part of the metre.

Each unit has its decimal multiples and submultiples, *i. e.*, weights and measures ten times larger or ten times smaller than the principal unit. These multiples and submultiples are indicated by prefixes to the names of the several fundamental units. The prefixes denoting multiples are derived from the Greek language, and are *deka*, ten; *hecto*, hundred; *kilo*, thousand; and *myria*, ten thousand; those denoting submultiples are taken from the Latin, and are *deci*, tenth; *centi*, hundredth; and *milli*, thousandth.

The following table includes all the weights and measures of the system:

RELATIVE VALUE.	LENGTH.	SURFACE.	CAPACITY.	SOLIDITY.	WEIGHT.
10,000	Myria-metre				
1,000	Kilo-metre		Kilo-litre		Kilo-gramme.
100	Hecto-metre	Hect-are	Hecto-litre		Hecto-gramme.
10	Deka-metre		Deka-litre	Deka-stere	Deka-gramme.
UNIT.	METRE.	ARE.	LITRE.	STERE.	GRAMME.
.1	Deci-metre	Deci-are	Deci-litre	Deci-stere	Deci-gramme.
.01	Centi-metre	Centi-are	Centi-litre		Centi-gramme.
.001	Milli-metre		Milli-litre		Milli-gramme.

The denominations of solid measure beyond the first multiple and submultiple by *ten* are not in use. The term *stere* itself is in fact rarely employed, measures of solidity or volume being usually expressed in cubic denominations of the linear base. Of agrarian measures, the only derivatives of the unit in use are the hectare, the deciare, and the centiare.

SUMMARY OF TABLES.—COMPARISON OF METRIC WITH

TABLE.			No.	LOGARITHM.
A.	Inches in a	Millimetre	0.039370432	$\bar{2}$.5951702
		Centimetre	0.39370432	$\bar{1}$.5951702
		Decimetre	3.9370432	0.5951702
		Metre	39.370432	1.5951702
	Feet in a	Decimetre	0.328086933	$\bar{1}$.5159890
		Metre	3.28086933	0.5159890
		Kilometre	3280.86933	3.5159890
	Yards in a	Metre	1.0936231I	0.0388677
		Kilometre	1093.62311	3.0388677
	Mile in a	Metre	0.000621377	$\bar{4}$.7933550
		Kilometre	0.621377	$\bar{1}$.7933550
B.	Square inches in a square	Millimetre	0.00155003	$\bar{3}$.1903404
		Centimetre	0.155003	$\bar{1}$.1903404
		Decimetre	15.5003	1.1903404
		Metre	1550.03	3.1903404
	Square feet in a square	Decimetre	0.10764104	$\bar{1}$.0319779
		Metre	10.764104	1.0319779
	Square yards in a square metre		1.1960115	0.0777354
C.	Cubic inches in a cube	Millimetre	0.000061025	$\bar{5}$.7855106
		Centimetre	0.061025394	$\bar{2}$.7855106
		Decimetre	61.02539436	1.7855106
		Metre	61025.39436	4.7855106
	Cubic feet in a cube	Decimetre	0.035315626	$\bar{2}$.5479669
		Metre	35.315626	1.5479669
	Cubic yards in a cubic metre		1.3079861	0.1166031
D.	Grains in a	Gramme	15.43234874	1.1884320
		Kilogramme	15432.34874	4.1884320
	Ounces (avoirdupois) in a	Gramme	0.035273935	$\bar{2}$.5474539
		Kilogramme	35.273935	1.5474539
	Pounds (avoirdupois) in a	Gramme	0.00220462132	$\bar{3}$.3433340
		Kilogramme	2.20462132	0.3433340
		Tonne (millier)	2204.62132	3.3433340
	Tons (2240 pounds) in a	Kilogramme	0.0009842059	$\bar{4}$.9930860
		Tonne	0.9842059I	$\bar{1}$.9930860
E.	Pounds to the square inch in an atmosphere		14.6967	1.1672200
	Ton to the square inch in an atmosphere		0.006561	$\bar{3}$.8169720
F.	Pounds to the inch in a kilogramme to the centimetre		5.59968718	0.7481638
	Tons to the foot in a tonne to the metre		0.29998255	$\bar{1}$.4770970

BRITISH OR UNITED STATES MEASURES, WEIGHTS, ETC.

LOGARITHM.	No.		TABLE.
1.4048298	25.399772	Millimetres ... }	
0.4048298	2.5399772	Centimetres ... } in an inch ...	
$\bar{1}$.4048298	0.25399772	Decimetre ... }	
$\bar{2}$.4048298	0.025399772	Metre ... }	
0.4840110	3.047972	Decimetres ... }	
1.4840110	0.3047972	Metre ... } in a foot ...	A.
$\bar{4}$.4840210	0.0003047972	Kilometre ... }	
$\bar{1}$.9611323	0.9143917	Metre ... }	
$\bar{4}$.9611323	0.0009143917	Kilometre ... } in a yard ...	
3.2066450	1609.33	Metres ... }	
0.2066450	1.60933	Kilometres ... } in a mile ...	
2.8096596	645.14836	Millimetres carrés. }	
0.8096596	6.4514836	Centimetres carrés. } in a square inch..	
$\bar{2}$.8096596	0.064514836	Decimetre carré... }	
$\bar{4}$.8096596	0.00064514836	Metre carré ... }	B.
0.9680221	9.29014	Decimetres carrés . }	
$\bar{2}$.9680221	0.0929014	Metre carré ... } in a square foot..	
$\bar{1}$.9222646	0.8361123	Metre carré in a square yard ...	
4.2144894	16386.61887	Millimetres cubes . }	
1.2144894	16.38661887	Centimetres cubes. } in a cubic inch ...	
$\bar{2}$.2144894	0.01638661887	Decimetre cube.... }	
$\bar{5}$.2144894	0.00001638662	Metre cube ... }	C.
1.4520331	28.3160784	Decimetres cubes.. }	
$\bar{2}$.4520331	0.0283160784	Metre cube ... } in a cubic foot ...	
$\bar{1}$.8833969	0.7645342	Metric cube in a cubic yard ...	
$\bar{2}$.8115680	0.064798955	Gramme ... } in a grain ...	
$\bar{5}$.8115680	0.00006479895	Kilogramme ... }	
1.4525461	28.3495454	Grammes ... } in an ounce avoir-	
$\bar{2}$.4525461	0.0283495454	Kilogramme ... } dupois ...	
2.6566660	453.59263	Grammes ... } in a pound avoir-	D.
$\bar{1}$.6566660	0.45359263	Kilogramme ... } dupois ...	
$\bar{4}$.6566660	0.00045359263	Tonne ... }	
3.0069140	1016.0474	Kilogrammes ... } in a ton (2,240	
0.0069140	1.0160474	Tonne ... } pounds) ...	
$\bar{2}$.8327800	0.06804245	Atmosphere in a pound to the square inch ...	E.
2.1830280	152.4150877	Atmospheres in a ton to the square inch	
$\bar{1}$.2518362	0.1785814	Kilogramme to the centimetre in a pound to the inch ...	F.
0.5229030	3.33351923	Tonnes to the metre in a ton to the foot	

SUMMARY OF TABLES.—COMPARISON OF METRIC WITH

TABLE.		No.	LOGARITHMS.
G.	Pounds to the square inch in a kilogramme to the square. — Millimetre.	1422.3078688	3.1529936
	Pounds to the square inch in a kilogramme to the square. — Centimetre.	14.223078688	1.1529936
	Ton to the square inch in a kilogramme to the square. — Millimetre...	0.63495884	$\bar{1}$.8027466
	Ton to the square inch in a kilogramme to the square. — Centimetre...	0.0063495884	$\bar{3}$.8027456
	Pounds to the square foot in a..... — Kilogramme to the square metre	0.204812311	$\bar{1}$.3113561
	Pounds to the square foot in a..... — Tonne..... to the square metre	204.812311	2.3113561
	Ton to the square foot in a..... — Kilogramme to the square metre.	0.000091434I	$\bar{5}$.9611081
	Ton to the square foot in a..... — Tonne..... to the square metre.	0.0914341	$\bar{2}$.9611081
H.	Pounds to the cubic inch in a kilogramme to the cubic millimetre...	36126.29166	4.5578234
	Pound to the cubic foot in a kilogramme to the cubic metre.....	0.06242623	$\bar{2}$.7953671
	Ton to the cubic foot in a tonne to the cubic metre.....	0.02786885	$\bar{2}$.4451191
I.	Foot-pounds in a kilogrammetre.....	7.233075	0.8593230
	Foot-tons in a tonne-metre.....	3.2290518	0.5090750
J.	Fahrenheit degrees in a Centigrade degree.....	1.8	0.2552725
	Fahrenheit degrees in a Réaumur degree.	2.25	0.3521825
K.	Units of heat in Calorie.....	3.96831835	0.5986065

BRITISH OR UNITED STATES MEASURES, WEIGHTS, ETC.

LOGARITHMS.	No.		TABLE.
$\bar{4}.8470064$	0.00070308274	Kilogramme to the Square millimetre.. in a pound to the square inch.....	G.
$\bar{2}.8470064$	0.070308274	Kilogramme to the Square centimetre. in a pound to the square inch.....	
0.1972544	1.57490507	Kilogrammes to the Square millimetre.. in a ton to the square inch	
2.1972544	157.490507	Kilogrammes to the Square centimetre. in a ton to the square inch	
0.6886439	4.88251819	Kilogrammes to the square metre in a pound to the square foot	
$\bar{3}.6886439$	0.00488251819	Tonne..... to the square metre in a pound to the square foot	
4.0388919	10936.84131	Kilogrammes to the square metre in a ton to the square foot	
1.0388919	10.93684131	Tonnes ..... to the square metre in a ton to the square foot	
$\bar{5}.4421766$	0.00002768067	Kilogramme to the cubic millimetre in a pound to the cubic inch	H.
1.2046329	16.0189	Kilogrammes to the cubic metre in a pound to the cubic foot	
1.5548809	35.882355	Tonnes to the cubic metre in a ton to the cubic foot	
$\bar{1}.1406770$	0.13825377	Kilogrammetres in a foot-pound.....	I.
$\bar{1}.4909250$	0.30968843	Tonne-metres in a foot-ton.....	
$\bar{1}.7447275$	0.5555555	Centigrade degree in a Fahrenheit degree	J.
$\bar{1}.6478175$	0.4444444	Réaumur degree in a Fahrenheit degree	
$\bar{1}.4013935$	0.25199593	Calorie in a unit of heat.....	K.

TABLE A.—

METRIC INTO BRITISH OR UNITED STATES.

Metres.		Inches.	Feet.	Yards.	Miles.
Millimetres.	0.001.	0.039370432			
	2	0.078740864			
	3.	0.118111296			
	4.	0.157481728			
	5.	0.196852160			
	6.	0.236222592			
	7.	0.275593024			
	8.	0.314963456			
	9.	0.354333888			
Centimetres.	0.01.	0.39370432			
	2.	0.78740864			
	3.	1.18111296			
	4.	1.57481728			
	5.	1.96852160			
	6.	2.36222592			
	7.	2.75593024			
	8.	3.14963456			
	9.	3.54333888			
Decimetres..	0.1.	3.9370432	0.3280869		
	2.	7.8740864	0.6561739		
	3.	11.8111296	0.9842608		
	4.	15.7481728	1.3123477		
	5.	19.6852160	1.6404346		
	6.	23.6222592	1.9685216		
	7.	27.5593024	2.2966085		
	8.	31.4963456	2.6246954		
	9.	35.3333888	2.9527824		
Metres.....	1.	39.370432	3.2808693	1.0936231	0.000621377
	2.	78.740864	6.5617386	2.1872462	0.001242754
	3.	118.111296	9.8426079	3.2808693	0.001864131
	4.	157.481728	13.1234772	4.3744924	0.002485508
	5.	196.852160	16.4043465	5.4681155	0.003106885
	6.	236.222592	19.6852158	6.5617386	0.003728262
	7.	275.593024	22.9660851	7.6553617	0.004349639
	8.	314.963456	26.2469544	8.7489848	0.004971016
	9.	354.333888	29.5278237	9.8426079	0.005592393
Kilometres .	1000.	.....	3280.8693	1093.6231	0.621377
	2	.....	6561.7386	2187.2462	1.242754
	3	.....	9842.6079	3280.8693	1.864131
	4	.....	13123.4772	4374.4924	2.485508
	5	.....	16404.3465	5468.1115	3.106885
	6	.....	19685.2158	6561.7386	3.728262
	7	.....	22966.0851	7655.3617	4.349639
	8	.....	26246.9544	8748.9848	4.971016
	9	.....	29527.8237	9842.6079	5.592393

MEASURES OF LENGTH.

BRITISH OR UNITED STATES INTO METRIC.

		Millimetres.	Centimetres.	Decimetres.	Metres.	Kilometres.
Inches.	1	25.39977	2.539977	0.2539977	0.02539977	
	2	50.79954	5.079954	0.5079954	0.05079954	
	3	76.19931	7.619931	0.7619931	0.07619931	
	4	101.59908	10.159908	1.0159908	0.10159908	
	5	126.99885	12.699885	1.2699885	0.12699885	
	6	152.39862	15.239862	1.5239862	0.15239862	
	7	177.79839	17.779839	1.7779839	0.17779839	
	8	203.19816	20.319816	2.0319816	0.20319816	
	9	228.59793	22.859793	2.2859793	0.22859793	
Feet	1	.....	.....	3.047972	0.3047972	0.0003047972
	2	.....	.....	6.095944	0.6095944	0.0006095944
	3	.....	.....	9.143916	0.9143916	0.0009143916
	4	.....	.....	12.191888	1.2191888	0.0012191888
	5	.....	.....	15.239860	1.5239860	0.0015239860
	6	.....	.....	18.287832	1.8287832	0.0018287832
	7	.....	.....	21.335804	2.1335804	0.0021335804
	8	.....	.....	24.383776	2.4383776	0.0024383776
	9	.....	.....	27.431748	2.7431748	0.0027431748
Yards	1	.....	.....	.....	0.9143917	0.0009143917
	2	.....	.....	.....	1.8287834	0.0018287834
	3	.....	.....	.....	2.7431751	0.0027431751
	4	.....	.....	.....	3.6575668	0.0036575668
	5	.....	.....	.....	4.5719585	0.0045719585
	6	.....	.....	.....	5.4863502	0.0054863502
	7	.....	.....	.....	6.4007419	0.0064007419
	8	.....	.....	.....	7.3151336	0.0073151336
	9	.....	.....	.....	8.2295253	0.0082295253
Miles.	1	.....	.....	.....	1609.33	1.60933
	2	.....	.....	.....	3218.66	3.21866
	3	.....	.....	.....	4827.99	4.82799
	4	.....	.....	.....	6437.32	6.43732
	5	.....	.....	.....	8046.66	8.04665
	6	.....	.....	.....	9655.98	9.65598
	7	.....	.....	.....	11265.31	11.26531
	8	.....	.....	.....	12874.64	12.87464
	9	.....	.....	.....	14483.97	14.48397

TABLE B.—SURFACE MEASUREMENTS.

METRIC INTO BRITISH OR UNITED STATES.

Square Metres.		Square Inches.	Square Feet.	Square Yards.
Square Millimetres.	0.000001	0.00155003		
	2	0.00310006		
	3	0.00465009		
	4	0.00620012		
	5	0.00775015		
	6	0.00930018		
	7	0.01085021		
	8	0.01240024		
	9	0.01395027		
Square Centimetres.	0.0001	0.155003		
	2	0.310006		
	3	0.465009		
	4	0.620012		
	5	0.775015		
	6	0.930018		
	7	1.085021		
	8	1.240024		
	9	1.395027		
Square Decimetres.	0.01	15.5003	0.10764104	
	2	31.0006	0.21528208	
	3	46.5009	0.32292312	
	4	62.0012	0.43056416	
	5	77.5015	0.53820520	
	6	93.0018	0.64584624	
	7	108.5021	0.75348728	
	8	124.0024	0.86112832	
	9	139.5027	0.96876936	
Square Metres.	1.	1550.03	10.764104	1.1960115
	2.	3100.06	21.528208	2.3920230
	3.	4650.09	32.292312	3.5880345
	4.	6200.12	43.056416	4.7840460
	5.	7750.15	53.820520	5.9800575
	6.	9300.18	64.584624	7.1760690
	7.	10850.21	75.348728	8.3720805
	8.	12400.24	86.112832	9.5680920
	9.	13950.27	96.876936	10.7641035

BRITISH OR UNITED STATES INTO METRIC.

		Square Millimetres.	Square Centimetres.	Square Decimetres.	Square Metres.
Square inches.	1.	645.14836	6.4514836	0.064514836	0.0006451484
	2.	1290.29672	12.9029672	0.129029672	0.0012902967
	3.	1935.44507	19.3544507	0.193544507	0.0019354451
	4.	2580.59343	25.8059343	0.258059343	0.0025805934
	5.	3225.74179	32.2574179	0.322574179	0.0032257418
	6.	3870.89015	38.7089015	0.387089015	0.0038708901
	7.	4516.03851	45.1603851	0.451603851	0.0045160385
	8.	5161.18686	51.6118686	0.516118686	0.0051611869
	9.	5806.33522	58.0633522	0.580633522	0.0058063352
Square feet.	1.	.....	.....	9.29014	0.0929014
	2.	.....	.....	18.58028	0.1858028
	3.	.....	.....	27.87042	0.2787042
	4.	.....	.....	37.16056	0.3716056
	5.	.....	.....	46.45070	0.4645070
	6.	.....	.....	55.74084	0.5574084
	7.	.....	.....	65.03098	0.6503098
	8.	.....	.....	74.32112	0.7432112
	9.	.....	.....	83.61126	0.8361126
Square yards.	1.	.....	.....	.....	0.8361123
	2.	.....	.....	.....	1.6722246
	3.	.....	.....	.....	2.5083369
	4.	.....	.....	.....	3.3444492
	5.	.....	.....	.....	4.1805615
	6.	.....	.....	.....	5.0166738
	7.	.....	.....	.....	5.8527861
	8.	.....	.....	.....	6.6888984
	9.	.....	.....	.....	7.5250107

TABLE C.—CUBIC MEASURES (VOLUMES).

METRIC INTO BRITISH OR UNITED STATES.

Cubic Metres.		Cubic inches.	Cubic feet.	Cubic yards.
Cubic Millimetres.	.000000001	0.000061025		
	2	0.000122051		
	3	0.000183076		
	4	0.000244102		
	5	0.000305127		
	6	0.000366152		
	7	0.000427178		
	8	0.000488203		
	9	0.000549228		
Cubic Centimetres.	0.000001	0.06102539		
	2	0.12205079		
	3	0.18307618		
	4	0.244101158		
	5	0.30512697		
	6	0.36615237		
	7	0.42717776		
	8	0.48820315		
	9	0.54922855		
Cubic Decimetres. (Litres.)	0.001	61.025394	0.03531563	
	2	122.050789	0.07063125	
	3	183.076183	0.10594688	
	4	244.101577	0.14126250	
	5	305.126972	0.17657813	
	6	366.152366	0.21189376	
	7	427.177761	0.24720938	
	8	488.203155	0.28252501	
	9	549.228549	0.31784063	
Cubic Metres.	1.	61025.39436	35.315626	1.3079861
	2.	122050.78882	70.631252	2.6159722
	3.	183076.18308	105.946878	3.9239583
	4.	244101.57744	141.262504	5.2319444
	5.	305126.97180	176.578130	6.5399305
	6.	366152.33616	211.893756	7.8479167
	7.	427177.76052	247.209382	9.1559028
	8.	488203.15488	282.525008	10.4638889
	9.	549228.54924	317.840634	11.7718750

BRITISH OR UNITED STATES INTO METRIC.

		Cubic Millimetres.	Cubic Centimetres.	Cubic Decimetres.	Cubic Metres.
				Litres.	
Cubic inches.	1.	16386.61887	16.38661887	0.0163866188	0.00001638662
	2.	32773.23774	32.77323774	0.0327732377	0.00003277324
	3.	49159.85661	49.15985661	0.0491598566	0.00004915986
	4.	65546.47548	65.54647548	0.0655464755	0.00006554647
	5.	81933.09435	81.93309435	0.0819330943	0.00008193309
	6.	98319.71322	98.31971322	0.0983197132	0.00009831971
	7.	114706.33209	114.70633209	0.1147063321	0.00011470633
	8.	131092.95096	131.09295096	0.1310929509	0.00013109295
	9.	137489.56983	147.47956983	0.1474795698	0.00014747957
Cubic feet.	1.	.....	.....	28.31608	0.02831608
	2.	.....	.....	56.63216	0.05663216
	3.	.....	.....	84.94824	0.08494824
	4.	.....	.....	113.26432	0.11326432
	5.	.....	.....	141.58040	0.14158040
	6.	.....	.....	169.89648	0.16989648
	7.	.....	.....	198.21256	0.19821256
	8.	.....	.....	226.52864	0.22652864
	9.	.....	.....	254.84472	0.25484472
Cubic yards.	1.	.....	.....	.....	0.764534
	2.	.....	.....	.....	1.529068
	3.	.....	.....	.....	2.263603
	4.	.....	.....	.....	3.058137
	5.	.....	.....	.....	3.822617
	6.	.....	.....	.....	4.587205
	7.	.....	.....	.....	5.351739
	8.	.....	.....	.....	6.116274
	9.	.....	.....	.....	6.880808

TABLE D.—Weights.

METRIC INTO UNITED STATES.

		Grains.	Ounces, (avoirdupois).	Pounds, (avoirdupois).	Tons, (2,240 pounds).
Grammes, (.001 of a kilog.).	1.	15.4323487	0.03527393	0.0022046213	
	2.	30.8646975	0.07054787	0.0044092426	
	3.	46.2970462	0.10582180	0.0066138640	
	4.	61.7293950	0.14109574	0.0088184853	
	5.	77.1617437	0.17636967	0.0110231066	
	6.	92.5940924	0.21164361	0.0132277279	
	7.	108.0264412	0.24691754	0.0154323492	
	8.	123.4587899	0.28219148	0.0176369706	
	9.	138.8911387	0.31746541	0.0198415919	
Kilogrammes.	1.	15432.349	35.27393	2.20462132	0.0009842059
	2.	30864.697	70.54787	4.40924264	0.0019684118
	3.	46297.046	105.82180	6.61386396	0.0029526177
	4.	61729.395	141.09574	8.81848528	0.0039367236
	5.	77161.744	176.36967	11.02310660	0.0049210295
	6.	92594.092	211.64361	13.22772792	0.0059052355
	7.	108026.441	246.91754	15.43234924	0.9068894414
	8.	123458.780	282.19148	17.63697056	0.0078736473
	9.	138891.139	317.46541	19.84159188	0.0088578532
Tonnes, (1,000 kilogrammes).	1.	.....	.....	2204.62132	0.9842059
	2.	.....	.....	4409.24264	1.9684118
	3.	.....	.....	6613.86396	2.9526177
	4.	.....	.....	8818.48528	3.9368236
	5.	.....	.....	11023.10660	4.9210295
	6.	.....	.....	13227.72792	5.9052355
	7.	.....	.....	15432.34924	6.8894414
	8.	.....	.....	17636.97056	7.8736473
	9.	.....	.....	19841.59188	8.8578532

UNITED STATES INTO METRIC.

		Grammes.	Kilogrammes.	Tonnes.
Grains.	1.	0.06479895	0.00006479895	
	2.	0.12956790	0.00012959790	
	3.	0.19439685	0.00019439685	
	4.	0.25919580	0.00025919580	
	5.	0.32399475	0.00032399475	
	6.	0.38879370	0.00038879370	
	7.	0.45359265	0.00045359265	
	8.	1.51839160	0.00151839160	
	9.	1.58319055	0.00158319055	
Ounces, (avoirdupois).	1.	28.3495454	0.028349545	
	2.	56.6990908	0.056699091	
	3.	85.0486362	0.085048636	
	4.	113.3981816	0.113398182	
	5.	141.7477270	0.141747727	
	6.	170.0972724	0.170097272	
	7.	198.4468178	0.198446818	
	8.	226.7963632	0.226796363	
	9.	255.1459086	0.255145909	
Pounds, (avoirdupois).	1.	453.59263	0.45359263	0.0004535926
	2.	907.18526	0.90718526	0.0009071853
	3.	1360.77789	1.36077789	0.0013607779
	4.	1814.37052	1.81437052	0.0018143705
	5.	2267.96315	2.26796315	0.0022679631
	6.	2721.55578	2.72155578	0.0027215558
	7.	3175.14741	3.17514841	0.0031751484
	8.	3628.74104	3.62874104	0.0036287410
	9.	4082.33367	4.08233367	0.0040823337
Tons (2,240 pounds).	1.	.....	1016.0474	1.0160474
	2.	.....	2032.0949	2.0320949
	3.	.....	3048.1423	3.0481423
	4.	.....	4064.1897	4.0641897
	5.	.....	5080.2371	5.0802371
	6.	.....	6096.2846	6.0962846
	7.	.....	7112.3320	7.1123320
	8.	.....	8128.3794	8.1283794
	9.	.....	9144.4269	9.1444269

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TABLE E.—PRESSURES IN ATMOSPHERES.

METRIC INTO BRITISH OR U. S.			BRITISH OR U. S. INTO METRIC.		
		Pounds on square inch.			Atmospheres, (met. system).
Atmospheres, (met. system).	1	14.6967	Pounds on the square inch.	1	0.06804245
	2	29.3934		2	0.13608490
	3	44.0901		3	0.20412735
	4	58.7868		4	0.27216980
	5	73.4835		5	0.34021225
	6	88.1802		6	0.40825470
	7	102.8769		7	0.47629715
	8	117.5736		8	0.54433960
	9	132.2703		9	0.61238205
		Tons on square inch.			Atmospheres, (met. system.)
Atmospheres, (met. system).	1	0.006561	Tons on the square inch.	1	152.4151
	2	0 013122		2	304.8302
	3	0.019683		3	457.2453
	4	0.026244		4	609.6604
	5	0.032805		5	762.0734
	6	0.039366		6	914.4905
	7	0.045927		7	1066.9056
	8	0.052488		8	1219.3207
	9	0.059049		9	1371.7358

TABLE F.—BENDING STRESS PER UNIT OF LENGTH.

METRIC INTO BRITISH OR U. S.			BRITISH OR U. S. INTO METRIC.		
		Pounds to the inch.			Kilogrammes to the centimetre.
Kilogrammes to the Centimetre.	1	5.599687	Pounds to the inch.	1	0.1785814
	2	11.199374		2	0.3571628
	3	16.799062		3	0.5357442
	4	22 398749		4	0.7143256
	5	27.998436		5	0.8929070
	6	33.598123		6	1.0714884
	7	39.197810		7	1.2500698
	8	44.797497		8	1.4286512
	9	50.397185		9	1.6072326
		Tons to the foot.			Tonnes to the metre.
Tonnes to the metre.	1	0.29998	Tons to the foot...	1	3.33352
	2	0.59996		2	6.66704
	3	0.89994		3	10.00056
	4	1.19993		4	13.33408
	5	1.49991		5	16.66760
	6	1.79989		6	20.00112
	7	2.09988		7	23.33464
	8	2.39986		8	26.66816
	9	2.69984		9	30.00168

TABLE G.—STRESS PER UNIT OF SQUARE MEASURE.

METRIC INTO BRITISH OR UNITED STATES.

		Pounds to the square inch.	Tons to the square inch.	Pounds to the square foot.	Tons to the square foot.
Kilogrammes to the square millimetre.	1	1422.30786	0.63495884		
	2	2844.61572	1.26991768		
	3	4266.92358	1.90487652		
	4	5689.23144	2.53983536		
	5	7111.53930	3.17479420		
	6	8533.84716	3.80975304		
	7	9956.15502	4.44471188		
	8	11378.46288	5.07967072		
	9	12800.77074	5.71462956		
Kilogrammes to the square centimetre.	1	14.2230786	0.006349588		
	2	28.4461572	0.012699176		
	3	42 6692358	0.019048765		
	4	56.8923144	0.025398354		
	5	71.1153930	0.031747942		
	6	85.3384716	0.038097530		
	7	99.5615502	0.044447119		
	8	113.7846288	0.050796707		
	9	128.0077074	0.057146296		
Kilogrammes to the square metre.	1	.....	.....	0.2048123	0.000091434 1
	2	.....	.....	0.4096246	0.0001828682
	3	.....	.....	0.6144369	0.0002743023
	4	.....	.....	0.8192492	0.0003657364
	5	.....	.....	1.0240615	0.0004571705
	6	.....	.....	1.2288738	0.0005486046
	7	.....	.....	1.4336861	0.0006400387
	8	.....	.....	1.6384984	0.0007314728
	9	.....	.....	1.8433107	0.0008229069
Tonnes to the square metre.	1	.....	.....	204.8123	0.0914341
	2	.....	.....	409.6246	0.1828682
	3	.....	.....	614.4369	0.2743023
	4	.....	.....	819.2492	0.3657364
	5	.....	.....	1024.0615	0.4571705
	6	.....	.....	1228.8738	0.5486046
	7	.....	.....	1433.6861	0.6400387
	8	.....	.....	1638.4984	0.7314728
	9	.....	.....	1843.3107	0.8229069

BRITISH OR UNITED STATES INTO METRIC.

		Kilog's to the sq. millimetre.	Kilog's to the sq. centimetre.	Kilog's to the sq. metre.	Tonnes to the sq. metre.
Pounds to the square inch.	1	0.0007030827	0.07030827		
	2	0.0014061654	0.14061664		
	3	0.0021092481	0.21092481		
	4	0.0028123308	0.28123308		
	5	0.0035154135	0.35154135		
	6	0.0042184962	0.42184962		
	7	0.0049215789	0.49215789		
	8	0.0056246616	0.56246616		
	9	0.0063277443	0.63277443		
Tons to the square inch.	1	1.57490507	157.490507		
	2	3.14981014	314.981014		
	3	4.72471521	472.471521		
	4	6.29962028	629.962028		
	5	7 87452535	787.452535		
	6	9.44943042	944.943042		
	7	11.02433549	1102.433549		
	8	12.59924056	1259.924056		
	9	14.17414563	1417.414563		
Pounds to the square foot.	1	.....	.....	4.882518	0.004882518
	2	.....	.....	9.765036	0.009765036
	3	.....	.....	14.647554	0.014647554
	4	.....	.....	19.530072	0.019530072
	5	.....	.....	24 412590	0.024412590
	6	.....	.....	29.295108	0.029295108
	7	.....	.....	34.177626	0.034177626
	8	.....	.....	39.060144	0.039060144
	9	.....	.....	43.942662	0.043942662
Tons to the square foot.	1	.....	.....	10936.84	10.93684
	2	.....	.....	21873.68	21.87368
	3	.....	.....	32810.52	32.81052
	4	.....	.....	43747.36	43.74736
	5	.....	.....	54684.19	54.68419
	6	.....	.....	65621.03	65.62103
	7	.....	.....	76557.87	76.55787
	8	.....	.....	87494.71	87.49471
	9	.....	.....	98431.55	98.43155

TABLE H.—STRESS PER UNIT OF CUBIC MEASURE.

METRIC INTO BRITISH OR U. S.			BRITISH OR U. S. INTO METRIC.		
		Pounds to the cubic inch.			Kilogr. to the millimetre cube.
Kilogrammes to the cubic millimetre.	1.	36126.29167	Pounds to the cubic inch.	1.	0.00002768067
	2.	72252.58333		2.	0.00005536134
	3.	108378.87500		3.	0.00008304201
	4.	144505.16667		4.	0.00011072268
	5.	180631.45833		5.	0.00013840335
	6.	216757.75000		6.	0.00016608402
	7.	252884.04167		7.	0.00019376469
	8.	289010.33333		8.	0.00022144536
	9.	325136.62500		9.	0.00024912603
		Pounds to the cubic foot.			Kilogr. to the metre cube.
Kilogrammes to the cubic metre.	1.	0.062426	Pounds to the cubic foot.	1.	16.0189
	2.	0.124852		2	32.0378
	3.	0.187279		3.	48.0567
	4.	0.249705		4.	64.0756
	5.	0.312131		5.	80.0945
	6.	0.374557		6.	96.1134
	7.	0.436984		7.	112.1323
	8.	0.499410		8.	128.1512
	9.	0.561836		9.	144.1701
		Tons to the cubic foot.			Tonnes to the metre cube.
Tonnes (1000 kilos.) to the cubic metre.	1.	0.02787	Tonnes to the cubic foot.	1.	35.882
	2.	0.05574		2.	71.764
	3.	0.08361		3.	107.647
	4.	0.11148		4.	143.529
	5.	0.13934		5.	179.411
	6.	0.16721		6.	215.294
	7.	0.19508		7.	251.176
	8.	0.22295		8.	287.058
	9.	0.25082		9.	322.941

TABLE I.—UNITS OF WORK OR ENERGY.

METRIC INTO BRITISH OR U. S.			BRITISH OR U. S. INTO METRIC.		
		Foot-pounds.			Kilogrammetres.
Kilogrammes.....	1	7.233075	Foot-pounds.....	1	0.13825377
	2	14.466150		2	0.27650755
	3	21.699225		3	0.41476133
	4	28.932300		4	0.55301511
	5	36.165375		5	0.69126888
	6	43.398450		6	0.82952266
	7	50.631525		7	0.96767644
	8	57.864600		8	1.10603022
	9	65.097675		9	1.24428399
		Foot-tons.			Metre-tonnes.
Metre-tonnes.....	1	3.2290518	Foot-tons.....	1	0.30968843
	2	6.4581036		2	0.61937686
	3	9.6871554		3	0.92906528
	4	12.9162072		4	1.23875371
	5	16.1452590		5	1.54844214
	6	19.3743108		6	1.85813057
	7	22.6033626		7	2.16781899
	8	25.8324144		8	2.47750742
	9	29.0614662		9	2.78719585

TABLE J.—THERMOMETERS.

CENTIGRADE DEGREES INTO FAHR.				FAHRENHEIT DEGREES INTO CENT.		
		Fahrenheit degrees.				Centigrade degrees.
Centigrade degrees.	1	1.8	+ 32	Fahr. degrees − 32	1	0.55555
	2	3.6			2	1.11111
	3	5.4			3	1.66666
	4	7.2			4	2.22222
	5	9.0			5	2.77777
	6	10.8			6	3.33333
	7	12.6			7	3.88888
	8	14.4			8	4.44444
	9	16.2			9	4.99999

RÉAUMUR DEGREES INTO FAHR.				FAHR. DEGREES INTO RÉAUMUR.		
		Fahrenheit degrees.				Réaumur degrees.
Réaumur degrees ..	1	2.25	+ 32	Fahr. degrees − 32	1	0.44444
	2	4.50			2	0.88888
	3	6.75			3	1.33333
	4	9.00			4	1.77777
	5	11.25			5	2.22222
	6	13.50			6	2.66666
	7	15.75			7	3.11111
	8	18.00			8	3.55555
	9	20.25			9	4.00000

TABLE K.—UNITS OF HEAT.

METRIC INTO BRITISH OR U. S.			BRITISH OR U. S. INTO METRIC.		
		U. S. units of heat.			Metric units of heat.
Metric units of heat (caloric).	1	3.96831835	U. S. units of heat.	1	0.25199593
	2	7.93663670		2	0.50399186
	3	11.90495505		3	0.75598779
	4	15.87327340		4	1.00798372
	5	19.84159175		5	1.25997965
	6	23.80991010		6	1.51197558
	7	27.77822845		7	1.76397151
	8	31.74654680		8	2.01596744
	9	35.71486515		9	2.26796337

CONVERSION TABLES.

BRITISH OR UNITED STATES, AND METRIC.

NOBLE.

CONVERSION TABLES.—NOBLE.

The following tables for conversion of British and Metric measures were compiled by Captain W. H. Noble, R. A., and supplied to the army by order of the Secretary of State for War.* The equivalents are given by tenths, units, tens, and hundreds, or by thousands. These tables or the preceding may be used indifferently, as may be convenient.

TABLE A.—KILOGRAMMES TO POUNDS AVOIRDUPOIS.

KILOS.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0.0	0.000	0.022	0.044	0.066	0.088	0.110	0.132	0.154	0.176	0.194
0.1	0.220	0.243	0.265	0.287	0.309	0.331	0.353	0.375	0.397	0.419
0.2	0.441	0.463	0.485	0.507	0.529	0.551	0.573	0.595	0.617	0.639
0.3	0·661	0.683	0.705	0.728	0.750	0.772	0.794	0.816	0.838	0.860
0.4	0.882	0.904	0.926	0.948	0.970	0.992	1.014	1.036	1.058	1.082
0.5	1.102	1.124	1.146	1.168	1.190	1.213	1.235	1.257	1.279	1.301
0.6	1.323	1.345	1.367	1.389	1.411	1.433	1.455	1.477	1.499	1.521
0.7	1.543	1.565	1.587	1.609	1.631	1.653	1.676	1.698	1.720	1.742
0.8	1.764	1.786	1.808	1.830	1.852	1.874	1.896	1.918	1.940	1.962
0.9	1.984	2.006	2.028	1.050	2.072	2.094	2.116	2.138	2.161	2.183
——	——	2.205	4.409	6.614	8.818	11.023	13.228	15.432	17.637	19.842
1	22.046	24.251	26.455	28.660	30.865	33.069	35.274	37.479	39.683	41.888
2	44.092	46.287	48.502	50.706	52.911	55.115	57.320	59.525	61.729	63.934
3	66.139	68.343	70.548	72.752	74.957	77.162	79.366	81.571	83.776	85.980
4	88.185	90.389	92.594	94.799	97.003	99.208	101.413	103.617	105.822	108.026
5	110.231	112.436	114.640	116.845	119.049	121.254	123.459	125.663	127.868	130.073
6	132.277	134.482	136.686	138.891	141.096	143.300	145.505	147.710	149.914	152.119
7	154.323	156.528	158.733	160.937	163.142	165.347	167.551	169.756	171.960	174.165
8	176.370	178.574	180.779	182.984	185.188	187.393	189.597	191.802	194.007	196.211
9	198.416	200.620	202.825	205.030	207.234	209.439	211.644	213.848	216.053	218.257
10	220.462									
20	440.924									
30	661.386									
40	881.848									
50	1102.311									
60	1322.773									
70	1543.235									
80	1763.697									
90	1984.159									
100	2204.621									
200	4409.24									
300	6613.86									
400	8818.48									
500	11023.11									
600	13227.73									
700	15432.35									
800	17636.97									
900	19841.59									
1000	22046.22									
2000	44092.44									
3000	66138.66									
4000	88184.88									
5000	110231.10									
6000	132277.32									
7000	154323.54									
8000	176369.76									
9000	198415.98									
10000	220462.20									

* London: Stationery Office, 1875.

TABLE B.

POUNDS TO KILOGRAMMES.

POUNDS.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0.0	0.000	0.005	0.009	0.014	0.018	0.023	0.027	0.032	0.036	0.041
0.1	0.045	0.050	0.054	0.059	0.064	0.068	0.073	0.077	0.082	0.086
0.2	0.091	0.095	0.100	0.104	0.109	0.113	0.118	0.122	0.127	0.132
0.3	0.136	0.141	0.145	0.150	0.164	0.159	0.163	0.168	0.172	0.177
0.4	0.181	0.186	0.191	0.195	0.200	0.204	0.209	0.213	0.218	0.222
0.5	0.227	0.231	0·236	0.240	0.245	0.249	0.254	0.259	0.263	0.268
0.6	2.272	0.277	0.281	0.286	0.290	0.295	0.299	0.304	0.208	0.313
0.7	0.318	0.322	0.327	0.331	0.336	0.340	0.345	0.449	0.358	0.354
0.8	0.363	0.367	0.371	0.376	0.381	0.386	0.390	0.395	0.399	0.409
0.9	0.408	0.413	0.417	0.422	0.426	0.431	0.435	0.440	0.445	0.442
—	—	0.454	0.907	1.361	1.814	2.268	2.722	3.175	3.629	4.088
1	4.536	4.989	5.443	5.897	6.350	6.804	7.257	7.711	8.165	8.614
2	9.072	9.525	9.979	10.433	10.886	11.340	11.793	12.247	12.701	13.150
3	13.608	14.061	14.015	14.969	15.422	15.876	16.329	16.783	17.236	17.698
4	18.144	18.597	19.551	19.504	19.958	20.412	20.865	21.319	21.772	22.226
5	22.680	23.133	23.587	24.040	24.494	24.948	25.401	25.855	26.308	26.762
6	27.216	27.669	28.123	28.576	29.030	29.483	29.937	30.391	30.844	31.298
7	31.751	32.205	32.659	33.112	33.566	34.019	34.473	34.927	35.380	35.834
8	36.287	36 741	37.195	37.648	38.102	38.555	39.009	39.463	39.916	40.370
9	40.823	41.277	41.730	42.184	42.638	43.091	43.545	43.998	44.452	44.906
10	45.36									
20	90 72									
30	136.08									
40	181.44									
50	226.80									
60	272.16									
70	317.52									
80	362.87									
90	408.23									
100	453.59									
200	907.18									
300	1360.77									
400	1814.36									
500	2267.95									
600	2721.54									
700	3175.13									
800	3628.72									
900	4087.31									
1000	4534.90									

TABLE C.

MILLIMETRES TO INCHES.

MILLI-METRES.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0.0	0.0000	0.0004	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028	0.0032	0.0035
0.1	0.0039	0.0043	0.0047	0.0051	0.0055	0.0059	0.0063	0.0067	0.0071	0.0075
0.2	0.0079	0.0083	0.0087	0.0091	0.0095	0.0098	0.0102	0.0106	0.0110	0.0114
0.3	0.0118	0.0122	0.0126	0.0130	0.0134	0.0138	0.0142	0.0146	0.0150	0.0154
0.4	0.0158	0.0161	0.0165	0.0169	0.0173	0.0177	0.0181	0.0185	0.0189	0.0193
0.5	0.0197	0.0201	0.0205	0.0209	0.0213	0.0217	0.0221	0.0224	0.0228	0.0232
0.6	0.0236	0.0240	0.0244	0.0248	0.0252	0.0256	0.0260	0.0264	0.0268	0.0272
0.7	0.0276	0.0280	0.0284	0.0287	0.0391	0.0295	0.0299	0.0303	0.0307	0.0311
0.8	0.0315	0.0319	0.0323	0.0327	0.0331	0.0335	0.0339	0.0343	0.0347	0.0350
0.9	0.0354	0.0358	0.0362	0.0366	0.0370	0.0374	0.0378	0.0382	0.0386	0.0389
——	——	0.039	0.079	0.118	0.157	0 197	0.236	0.276	0.315	0.354
1	0.394	0.433	0.472	0.512	0.551	0.591	0.630	0.669	0.709	0.748
2	0.787	0.827	0.866	0.905	0.945	0.984	1.024	1.063	1.102	1.142
3	1.181	1.220	1.260	1.299	1.339	1.378	1.417	1.457	1.496	1.535
4	1.575	1.614	1.654	1.693	1.732	1.772	1·811	1.850	1.890	1.929
5	1.968	2.008	2.047	2.087	2.126	2.165	2.205	2.244	2.283	2.323
6	2.362	2.402	2:441	2.480	2.520	2.559	2.598	2.638	2.677	2.717
7	2.756	2.795	2.835	2.847	2.913	2.953	2.992	3.031	3.071	3.110
8	3.150	3.189	3.228	3.268	3.307	3.346	3.386	3.425	3.465	3.504
9	3.543	3.583	3.622	3.661	3.701	3.740	3.780	3.819	3.858	3.898
10	3.937									
20	7.874									
30	11.811									
40	15.748									
50	19.685									
60	23 622									
70	27.559									
80	31.497									
90	35.434									
100	39 371									
200	78.742									
300	118.112									
400	157.483									
500	196.854									
600	236.225									
700	265.595									
800	314.966									
900	354.337									
1000	393.708									

TABLE D.—METRES TO FEET.

Metres.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0.0	0.000	0.033	0.066	0.098	0.131	0.164	0.197	0.230	0.262	0.295
0.1	0.328	0.361	0.394	0.426	0.459	0.492	0.525	0.558	0.590	0.623
0.2	0.656	0.689	0.722	0.754	0.787	0.820	0.853	0.886	0.918	0.951
0.3	0.984	1.017	1.050	1.082	1.115	1.148	1.181	1.214	1.246	1.279
0.4	1.312	1.345	1.378	1.410	1.443	1 476	1.509	1.542	1.574	1.607
0.5	1.640	1.673	1.706	1.738	1.771	1.804	1.837	1.870	1.902	1.935
0.6	1.968	2.001	2.034	2.067	2.100	2.142	2.165	2.198	2.230	2.263
0.7	2.296	2.329	2.362	2.394	2.427	2.460	2.493	2.526	2.558	2.591
0.8	2.624	2.657	2.690	2.722	2.755	2.788	2.821	2.854	2.886	2.919
0.9	2.952	2.985	3.018	3.050	3.083	3.116	3.149	3.182	3.214	3.247
—	—	3.281	6.562	9.843	13.124	16.405	19.685	22.966	26.247	29.528
1	32.809	36.090	39.371	42.652	45.933	49.213	52.494	55.775	59.056	62.337
2	65.618	68.899	72.180	75.461	78.771	82.022	85.304	88 584	91.865	95.146
3	98.427	101.708	104.989	108.270	111.550	114.831	118.112	121.393	124.674	127.955
4	131.236	134.517	137.798	141.079	144.360	147.640	150.921	154.202	157.483	160.764
5	194.045	167.326	170.607	173.888	177.169	180.449	183.730	187.011	190.292	193.573
6	196.854	200.135	203.416	206.697	209.978	213.258	216.539	219.820	223.101	226.382
7	229.663	232.944	236.225	239.506	242.785	246.067	249.349	252.629	255.910	259.191
8	262.472	265.753	269.034	272.315	275.595	278.876	282.157	285.438	288.719	292.000
9	295.281	298.562	301.843	305.124	308.405	311.685	314.966	318.247	321.528	324.809
10	328.09									
20	656.18									
30	984.27									
40	1312.36									
50	1640.45									
60	1968.54									
70	2296.63									
80	2424.72									
90	2952.81									
100	3280.91									
200	6561.80									
300	9842.70									
400	13123.60									
500	16404.50									
600	19685.39									
700	22966.29									
800.	26247.19									
900	29528.09									
1000	32808.99									

TABLE E.—CUBIC CENTIMETRES TO CUBIC INCHES.

Cubic Centi-metres.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
—	—	0.061	0.122	0.183	0.244	0.305	0.366	0.427	0.488	0.549
1	0.610	0.671	0.732	0.793	0.854	0.915	0.976	1.037	1.098	1.159
2	1.220	1.282	1.343	1.404	1.465	1.526	1.587	1.648	1.709	1.770
3	1.831	1.892	1.953	2.014	2.075	2.136	2.997	2.258	2.319	2.380
4	2.441	2.502	2.563	2.624	2.685	2.746	2.807	2.868	2.927	2.990
5	3.051	3.112	3.173	3.234	3.295	3.356	3.417	3.478	3.540	3 601
6	3.662	3.723	3.784	3.845	3.906	3.967	4.028	4.089	4.150	4.211
7	4.272	4.333	4.394	4.455	4.516	4.577	4.638	4.699	4.760	4.821
8	4.882	4.943	5.004	5.065	5.126	5.187	5.248	5.309	5.370	5.431
9	5.492	5.553	5.614	5.675	5.736	5.798	5.859	5.920	5.981	6.042
10	6.103									
20	12.205									
30	18.308									
40	24.410									
50	30.513									
60	36.615									
70	42.718									
80	48.820									
90	54.923									
100	61.025									

TABLE F.—INCHES TO MILLIMETRES.

Inches.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9
0.0	0.000	0.254	0.508	1.762	1.016	1.278	1.524	2.778	2.032	2.286
0.1	2.540	2.794	3.048	3.302	3.556	3.810	4.064	4.318	4.572	4.826
0.2	5.080	5.334	5.588	5.842	6.096	6.350	6.604	6.358	7.112	7.366
0.3	7.620	7.874	8.128	8.382	8.636	8.890	9.144	9.398	9.652	9.906
0.4	10.160	10.414	10.668	10.922	11.176	11.430	11.684	11.938	12.192	12.446
0.5	12.700	12.954	13.208	13.462	13.716	13.970	14.224	14.478	14.732	14.986
0.6	15.240	15.494	15.748	16.002	16.256	16.510	16.764	17.018	17.272	17.526
0.7	17.780	18.034	18.288	18.542	18.796	19.050	19.304	19.558	19.812	20.066
0.8	20.320	20.574	20.828	21.082	21.336	21.590	21.844	22.098	22.352	22.606
0.9	22.860	23.114	23.368	23.622	23.876	24.139	24.384	24.638	24.892	24.146
—	—	25.400	50.800	76.199	101.599	127.000	152.399	177.798	203.198	228.598
1	254.0	279.4	304.8	330.2	355.6	381.0	406.4	431.8	457.2	482.6
2	508.0	533.4	558.8	584.2	609.6	635.0	660.4	685.8	711.2	736.6
3	762.0	787.4	812.8	838.2	863.6	889.0	914.4	939.8	965.2	990.6
4	1016.0	1041.4	1066.8	1092.2	1117.6	1143.9	1168.4	1193.8	1219.2	1244.6
5	1272.0	1295.4	1320.8	1346.2	1371.6	1397.0	1422.4	1447.8	1473.2	1498.6
6	1524.0	1549.4	1574.8	1600.2	1625.6	1651.0	1676.4	1701.8	1727.2	1752.6
7	1778.0	1803.4	1828.8	1854.2	1879.6	1905.0	1930.4	1955.8	1981.2	2006.6
8	2032.0	2057.4	2082.8	2108.2	2133.6	2159.0	2184.4	2209.8	2235.2	2260.6
9	2286.0	2311.4	2336.8	2362.2	2387.6	2413 0	2438.4	2463.8	2489.2	2514.6
10	2,540									
20	5,080									
30	7,620									
40	10,160									
50	12,700									
60	15,240									
70	17,780									
80	20,320									
90	22,860									
100	25,400									

TABLE G.—FEET TO METRES.

Feet.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0.0	0.000	0.003	0.006	0.009	0.012	0.015	0.018	0.021	0.024	0.027
0.1	0.030	0.033	0.037	0.040	0.043	0.046	0.049	0.052	0.055	0.058
0.2	0.061	0.064	0.067	0.070	0.073	0.076	0.079	0.082	0.085	0.088
0.3	0.091	0.094	0.097	0.100	0.104	0.107	0.110	0.113	0.116	0.119
0.4	0.122	0.125	0.128	0.131	0.134	0.137	0.140	0.143	0.146	0.149
0.5	0.152	0.155	0.158	0.161	0.164	0.168	0.171	0.174	0.177	0.180
0.6	0.183	0.186	0.189	0.192	0.195	0.198	0.201	0.204	0.207	0.210
0.7	0.213	0.216	0.219	0.222	0.226	0.229	0.232	0.235	0.238	0.241
0.8	0.244	0.247	0.250	0.253	0.256	0.259	0.262	0.265	0.268	0.271
0.9	0.274	0.277	0.280	0.283	0.286	0.289	0.293	0.296	0.299	0.302
—	—	0.305	0.610	0.914	1.219	1.524	1.829	2.134	2.438	2.743
1	3.048	3.353	3.657	3.962	4.267	4.572	4.877	5.181	5.486	5.791
2	6.096	6.401	6.705	7.010	7.315	7.620	7.925	8.229	8.534	8.839
3	9.144	9.449	9.753	10.058	10.363	10.668	10.973	11.277	11.582	11.887
4	12.192	12.497	12.801	13.106	13.411	13.716	14.020	14.325	14.630	14.635
5	15.240	15.544	15.849	16.154	16.495	16.764	17.068	17.373	17.678	17.983
6	18.288	18.592	18.897	19.202	19.507	19.812	20.116	20.421	20.726	21.031
7	21.336	21.640	21.945	22.250	22.555	22.860	23.164	23.469	23.774	24.079
8	24.384	24.688	24.993	25.298	25.603	25.907	26.212	26.517	26.822	27.127
9	27.431	27.736	28.041	28.346	28.651	28.955	29.260	29.565	29.870	30.175
10	30.479									
20	60.959									
30	91.438									
40	121.918									
50	152.397									
60	182.877									
70	213.356									
80	243.836									
90	274.315									
100	304.79									
200	609.59									
300	914.38									
400	1219.18									
500	1523.97									
600	1828.77									
700	2133.56									
800	2438.36									
900	2743.15									
1,000	3077.94									

TABLE H.

CUBIC INCHES TO CUBIC CENTIMETRES.

Cubic Inches.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0.	0.000	1.639	3.277	4.916	6.555	8.193	9.832	11.470	13.109	14.748
—	—	16.386	32.772	49.158	65.545	81.931	98.317	114.70	131.09	147.48
1	163.86	180.25	196.63	213.02	229.41	245.79	262.18	278.57	294.95	311.34
2	327.72	344.11	360.50	376.88	393.27	409.65	426.04	442.43	458.81	475.20
3	491.59	507.87	524.46	540.84	557.23	573.62	590.00	606.39	622.68	639.06
4	655.45	671.83	688.22	704.61	720.99	737.38	753.76	770.15	786.54	802.92
5	819.31	835.70	852.08	868.47	884.85	901.24	917.63	934.01	950.40	966.78
6	983.17									
7	1147.32									
8	1310.89									
9	1474.76									
10	1638.62									

TABLE I.

TONS PER SQUARE INCH TO KILOGRAMMES PER SQUARE CENTIMETRE, AND VICE VERSA.

Tons per sq. inch.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0.00	0.0000	0.1575	0.3150	0.4275	0.6300	0.7875	0.9450	1.1024	1.2599	1.4174
0.01	1.5749	1.7324	1.8899	2.0474	2.2049	2.3624	2.5199	2.6774	2.8349	2.9924
0.02	3.1499	3.3074	3.4648	3.6223	3.7798	3.9373	4.0948	4.2523	4.4098	4.5673
0.03	4.7248	4.8823	5.0938	5.1973	5.3548	5.5123	5.6698	5.8272	5.9847	6.1422
0.04	6.2997	6.4572	6.6147	6.7722	6.9297	7.0872	7.2447	7.4022	7.5597	7.7172
0.05	7.8747	8.0322	8 1896	8.3471	8.5046	8·6621	8.8196	8.9771	9.1346	9.2921
0.06	9.4496	9.6071	9.7646	9.9221	10.080	10.237	10.395	10.552	10.710	10.867
0.07	11.025	11.182	11.340	11.497	11.655	11.812	11.970	12.127	12.285	12.442
0.08	12.600	12.757	12.915	13.072	13.229	13.387	13.544	13.702	13.859	14.017
0.09	14.174	14.332	14.489	14.650	14.804	14.962	15.119	15.277	15.434	15.592
0.	—	15.749	31.499	47.248	62.997	78.747	94.496	11.025	12.600	14.174
—	—	157.49	314.99	472.48	629.97	787.47	944.96	1102.5	1259.9	1417.4
1	1574.9	1732.4	1889.9	2047.4	2204.9	2362.4	2519.9	2677.4	2834.9	2992.4
2	3149.9	3307.4	3464.8	3622.3	3779.8	3937.3	4094.8	4252.3	4409.8	4567.3
3	4724.8	4882.3	5039.8	5197.3	5354.8	5512.3	5669.8	5827.2	5984.7	6142.2
4	6299.7	6457.2	6614.7	6772.2	6929.7	7087.2	7244.7	7402.2	7559.7	7717.2
5	7874.7									
6	9449.6									
7	11025									
8	12600									
9	14174									
100	15749									

ADDITIONAL CONVERSION TABLES.

ADDITIONAL CONVERSION TABLES.

THE following Additional "Conversion Table" will be useful in transforming measures in special cases:

TABLE A.

SIXTEENTHS OF AN INCH TO MILLIMETRES.

INCH.	0	1/16	1/8	3/16	1/4	5/16	3/8	7/16
0		1.587	3.175	4.762	6.350	7.937	9.525	11.112
1	25.400	26.987	28.574	30.162	31.749	33.337	34.924	36.512
2	50.799	52.387	53.974	55.561	57.149	58.736	60.324	61.911
3	76.199	77.786	79.374	80.961	82.549	84.136	85.733	87.311
4	101.60	103.19	104.77	106.36	107.93	105.954	111.12	112.71
5	127.00	128.59	130.17	131.76	133.35	134.94	136.52	138.11
6	152.40	153.98	155.57	157.16	158.75	160.33	161.92	163.51
7	177.80	179.38	180.97	182.56	184.15	185.73	187.32	188.91
8	203.20	204.78	206.37	207.96	209.55	211.13	212.72	214.31
9	228.60	230.18	231.77	233.36	234.95	236.33	238.12	239.71
10	254.00	255.58	257.17	258.76	260.35	261.93	263.52	265.11
11	279 39	280.98	282.57	284.16	285.74	287.33	288.92	290.51
12	304.79	306.38	307.97	309.56	311.14	312.73	314.32	315.91
13	330.19	331.78	333.37	334.96	336.54	338.13	339.72	341.31
14	355.59	357.18	358.77	360.36	361.94	363.53	365.12	366.71
15	380.99	382.58	384.17	385.76	387.34	388.93	390.52	392.11
16	406.39	407.98	409.57	411.16	412.74	414.33	415.92	417.50
17	431.79	433.38	434.97	436.55	438.14	439.73	441.32	442.90
18	457.19	458.78	460.37	461.95	463.54	465.13	466.72	468.30
19	482.59	484.18	485.77	487.35	488.94	490.53	492.12	493.70
20	507.99	509.58	511.17	512.75	514.34	515.93	517.52	519.10
21	533.39	534.98	536.57	538.15	539.74	541.33	542.92	544.50
22	558.79	560.38	561.96	563.55	565.14	566.73	568.31	569.90
23	584.19	585.78	587.36	588.95	590.54	592.13	593.71	595.30
24	609.59	611.18	612.76	614.35	615.94	617.53	619.11	620.70
25	634.99	636.58	638.16	639.75	641.34	642.93	644.51	646.10
26	660.39	661.98	663.56	665.15	666.74	668.33	669.91	671.50
27	685.79	687.38	688.96	690.55	692.14	693.72	695.31	696.90
28	711.19	712.77	714.36	715.95	717.54	719.12	720.71	722.30
29	736.59	738.17	739.76	741.35	742.94	744.52	746.11	747.70
30	761.99	763.57	765.16	766.75	768.34.	769.92	771.51	773.10
31	787.39	788.97	790.56	792.15	793.74	795.32	796.91	798.50
32	812.79	814.37	815.96	817.55	819.14	820.72	822.31	823.90
33	838.18	839.77	841.36	842.95	844.53	846.12	847.71	849.30
34	863.58	865.17	866.76	868.25	869.93	871.52	873.11	874.70
35	888.98	890.57	892.16	893.75	895.33	896.92	898.51	900.10

TABLE A.—*continued.*

SIXTEENTHS OF AN INCH TO MILLIMETRES.

INCH.	1/16	3/16	5/16	7/16	9/16	11/16	13/16	15/16
0	12.700	14.287	15.875	17.462	19.050	20.637	22.225	23.812
1	38.099	39.687	41.274	42.863	44.449	46.037	47.624	49.212
2	63.499	65.086	66.674	68.261	69.869	71.436	73.024	74.611
3	88.898	90.486	92.073	93.661	95.248	96.836	98.423	100.01
4	114.30	115.89	117.47	119.06	120.65	122.24	123.82	125.41
5	139.70	141.28	142.87	144.46	146.05	147.63	149.92	150.81
6	165.10	166.68	168.27	169.86	171.45	173.03	174.62	176.21
7	190.50	192.08	193.67	195.26	196.85	198.43	200.02	201.61
8	215.90	217.48	219.07	220.66	222.25	223.83	225.43	227.01
9	241.30	242.88	244.47	246.06	247.65	249.23	250.82	252.41
10	266.70	268.28	269.87	271.46	273.05	274.63	276.22	277.81
11	292.09	293.68	295.27	296.86	298.44	300.03	301.62	303.21
12	317.49	319.08	320.67	322.26	323.84	325.43	327.02	328.61
13	342.89	344.48	346.07	347.66	349.24	350.83	352.42	354.01
14	368.29	369.88	371.47	373.06	374.64	376.23	377.82	379.41
15	393.69	395.28	396.87	398.46	400.04	401.63	403.22	404.81
16	419.09	420.68	422.27	423.85	425.44	427.05	428.62	430.20
17	444.49	446.08	447.67	449.25	450.84	452.43	454.02	455.60
18	469.89	471.48	473.07	474.65	476.24	477.83	479.42	481.00
19	495.29	496.88	498.47	500.05	501.64	503.23	504.82	506.40
20	520.69	522.38	523.87	525.45	527.04	528.63	530.22	531.80
21	546.09	547.68	549.87	550.85	552.44	554.03	555.61	557.20
22	571.49	572.08	574.66	576.25	577.84	579.43	581.01	582.60
23	596.89	598.48	600.06	601.65	603.24	504.83	6c6.41	608.00
24	622.29	623.88	625.46	627.05	628.64	630.23	631.81	633.40
25	647.69	649.28	650.86	652.45	654.04	655.63	657.21	658.80
26	673.09	674.68	676.26	677.85	679.44	681,03	682.61	684.20
27	698.49	700.07	701.66	703.25	704.84	706.42	708.01	709.60
28	723.89	725.47	727.06	728.65	730.24	731.82	733.41	735.00
29	749.29	750.87	752.46	754.05	755.64	757.22	758.81	760.40
30	774.69	776.27	777.86	779.45	781.04	782.62	784.21	785.80
31	800.09	801.67	803.26	804.85	806.44	808.02	809.61	811.20
32	825.49	827.07	828.66	830.25	831.83	833.42	835.01	836.60
33	850.88	852.47	854.06	855.65	857.23	858.82	860.41	862.00
34	876.28	877.87	879.46	881.05	882.63	884.22	885.81	887.40
35	901.68	903.27	904.86	906.15	908.03	909.62	911.21	912.80

TABLE B.

THERMOMETRICAL SCALES.

TABLE showing the relative proportions of Fahrenheit's, Réaumur's, and the Centigrade thermometrical scales :—

F.	R.	C.	F.	R.	C.	F.	R.	C.	F.	R.	C.	F.	R.	C.
212	80.0	100.0	163	58 2	72.7	114	36.4	45.5	65	14.6	18.3	16	— 7.1	— 8.8
211	79.5	99.4	162	57.7	72.2	113	36.0	45.0	64	14.2	17.7	15	— 7.5	— 9.5
210	79.1	98.8	161	57.3	71.6	112	35.5	44.4	63	13.7	17.2	14	— 8.0	—10.0
209	78.6	98.3	160	56.8	71.1	111	35.1	43.8	62	13.3	16.6	13	— 8.4	—10.5
208	78.2	97.7	159	56.4	70.5	110	34.6	43.3	61	12.8	16.1	12	— 8.8	—11.1
207	77.7	97.2	158	56.0	70.0	109	34.2	42.7	60	12.4	15.5	11	— 9.3	—11.6
206	77.3	96.6	157	55.5	69.4	108	33.7	42.2	59	12.0	15.0	10	— 9.7	—12.2
205	76.8	96.1	156	55.1	68.8	107	33.3	41.6	58	11.5	14.4	9	—10.2	—12.7
204	76.4	95.5	155	54.6	68.3	106	32.8	41.1	57	11.1	13.8	8	—10.6	—13.3
203	76.0	95.0	154	54.2	67.7	105	32.4	40.5	56	10.6	13.3	7	—11.1	—13.8
202	75.5	94.4	153	53.7	67.2	104	32.0	40.0	55	10.2	12.7	6	—11.5	—14.4
201	75.1	93.8	152	55.3	66.6	103	31.5	39.4	54	9.7	12.2	5	—12.0	—15.0
200	74.6	93.3	151	52.8	66.1	102	31.1	38.8	53	9.3	11.6	4	—12.4	—15.5
199	74.2	92.7	150	52.4	65.5	101	30.6	38.3	52	8.8	11.1	3	—12.8	—16.1
198	73.7	92.2	149	52.0	65.0	100	30.2	37.7	51	8.4	10.5	2	—13.3	—16.6
197	73.8	91.6	148	51.5	64.4	99	29.7	37.2	50	8.0	10.0	1	—13 7	—17.2
196	72.8	91.1	147	51.1	63.8	98	29.3	36.6	49	7.5	9.4	0	—14.2	—17.7
195	72.4	90.5	146	50.6	63.3	97	28.8	36.1	48	7.1	8.8	— 1	—14.6	—18.3
194	72.0	90.0	145	50.2	62.7	96	28.4	35.5	47	6.6	8.3	— 2	—15.1	—18.8
193	71.5	89.4	144	49.7	62.2	95	28.0	35.0	46	6.2	7.7	— 3	—15.5	—19.4
192	71.1	88.8	143	49.3	61.6	94	27.5	34.4	45	5.7	7.2	— 4	—16.0	—20.0
191	70.6	88.3	142	48.8	61.1	93	27.1	33.8	44	5.3	6.6	— 5	—16.4	—20.5
190	70.2	87.7	141	48.4	60.5	92	26.6	33.3	43	4.8	6.1	— 6	—16.8	—21.1
189	69.7	87.2	140	48.0	60.0	91	26.2	32.7	42	4.4	5.5	— 7	—17.3	—21.6
188	65.3	86.6	139	47.5	59.4	90	25.7	32.2	41	4.0	5.0	— 8	—17.7	—22.2
187	68.8	86.1	138	47.1	58.8	89	25.3	31.6	40	3.5	4.4	— 9	—18.2	—22.7
186	68.4	85.5	137	46.6	58.3	88	24.8	31.1	39	3.1	3.8	—10	—18.6	—23 3
185	68.0	85.0	136	46.2	57.7	87	24.4	30.5	38	2.6	3.3	—11	—19.1	—23.8
184	67.5	84.4	135	45.7	57.2	86	24.0	30.0	37	2.2	2.7	—12	—19.5	—24.4
183	67.1	83.8	134	45.3	56.6	85	23.5	29.4	36	1.7	2.2	—13	—20.0	—25.0
182	66.6	83.3	133	44.8	56.1	84	23.1	28.8	35	1 3	1.6	—14	—20.4	—25.5
181	66.2	82.7	132	44.4	55.5	83	22.6	28.3	34	0.8	1.1	—15	—20.8	—26.1
180	65.7	82.2	131	44.0	55.0	82	22.2	27.7	33	0.4	0.5	—16	—21.3	—26.6
179	65.3	81 6	130	43.5	54.4	81	21.7	27.2	32	0.0	0.0	—17	—21.7	—27.2
178	64.8	81.1	129	43.1	53.8	80	21.3	26.6	31	—0.4	—0.5	—18	—22.2	—27.7
177	64.4	80.5	128	42.6	53.3	79	20.8	26.1	30	—0.8	—1.1	—19	—22.6	—28.3
176	64.0	80.0	127	42.2	52.7	78	20.4	25.5	29	—1.3	—1.6	—20	—23.1	—28 8
175	63.5	79.4	126	41.7	52.2	77	20.0	25.0	28	—1.7	—2.2	—21	—23.5	—29.4
174	63.1	78.8	125	41.3	51.6	76	19.5	24.4	27	—2.2	—2.7	—22	—24.0	—30.0
173	62.6	78.3	124	40.8	51.1	75	19.1	23.8	26	—2.6	—3.3	—23	—24.4	—30.5
172	62.2	77.7	123	40.4	50.5	74	18.6	23.3	25	—3.1	—3.8	—24	—24.8	—31.1
171	61.7	77.2	122	40.0	50.0	73	18.2	22.7	24	—3.5	—4.4	—25	—25.3	—31.6
170	61.3	76.6	121	39.5	49.4	72	17.7	22.2	23	—4.0	—5.0	—26	—25.7	—32.2
169	60.8	75.1	120	39.1	48.8	71	17.3	21.6	22	—4.4	—5.5	—27	—26.2	—32.7
168	60.4	75.5	119	38.6	48.3	70	16.8	21.1	21	—4.8	—6.1	—28	—26.6	—33.3
167	60.0	75.0	118	38.2	47.7	69	16.4	20.5	20	—5.3	—6.6	—29	—27.1	—33.8
166	59.5	74.4	117	37.7	47.2	68	16.0	20.0	19	—5.7	—7.2	—30	—27.5	—34.4
165	59.1	73.8	116	37.3	46.6	67	15.5	19.4	18	—6.2	—7.7	—31	—28.0	—35.0
164	58.6	73.3	115	36.8	46.1	66	15.1	18.8	17	—6.6	—8.3			

Freezing Point.		Boiling Point.	
Fahrenheit	= 32°	Fahrenheit	= 212°
Centigrade	= 0°	Centigrade	= 100°
Réaumur	= 0°	Réaumur	= 80°

To convert Fahrenheit into Centigrade: $\frac{5\,(F-32)}{9}$ = Centigrade.

To convert Centigrade into Fahrenheit: $\frac{9\,C}{5} + 32$ = Fahrenheit.

To convert Fahrenheit into Réaumur: $\frac{4\,(F-32)}{9}$ = Réaumur.

To convert Réaumur into Fahrenheit: $\frac{9\,R}{4} + 32$ = Fahrenheit.

TABLE C.

TABLE OF INCHES AND SIXTEENTHS REDUCED TO DECIMALS OF A FOOT.

INCH.	FEET.	INCH.	FEET.	INCH.	FEET.	INCH.	FEET.	INCH.	FEET.	INCH.	FEET.
0	.0000	2	.1667	4	.3333	6	.5000	8	.6667	10	.8333
	.0052		.1719		.3385		.5052		.6719		.8385
1/16	.0104	1/16	.1771	1/16	.3438	1/16	.5104	1/16	.6771	1/16	.8438
	.0156		.1823		.3490		.5156		.6823		.8490
1/8	.0208	1/8	.1875	1/8	.3542	1/8	.5208	1/8	.6875	1/8	.8542
	.0260		.1927		.3594		.5260		.6927		.8594
3/16	.0313	3/16	.1979	3/16	.3646	3/16	.5313	3/16	.6979	3/16	.8646
	.0365		.2031		.3698		.5365		.7031		.8698
1/4	.0417	1/4	.2083	1/4	.3750	1/4	.5417	1/4	.7083	1/4	.8750
	.0469		.2135		.3802		.5469		.7135		.8802
5/16	.0521	5/16	.2188	5/16	.3854	5/16	.5521	5/16	.7188	5/16	.8854
	.0573		.2240		.3906		.5573		.7240		.8906
3/8	.0625	3/8	.2292	3/8	.3958	3/8	.5625	3/8	.7292	3/8	.8958
	.0677		.2344		.4010		.5677		.7344		.9010
7/16	.0729	7/16	.2396	7/16	.4063	7/16	.5729	7/16	.7396	7/16	.9063
	.0781		.2448		.4115		.5781		.7448		.9115
1	.0833	3	.25	5	.4167	7	.5833	9	.7500	11	.9167
	.0885		.2552		.4219		.5885		.7552		.9219
1/16	.0938	1/16	.2604	1/16	.4271	1/16	.5938	1/16	.7604	1/16	.9271
	.0990		.2656		.4323		.5990		.7656		.9323
1/8	.1042	1/8	.2708	1/8	.4375	1/8	.6042	1/8	.7708	1/8	.9375
	.1094		.2760		.4427		.6094		.7760		.9427
3/16	.1146	3/16	.2813	3/16	.4479	3/16	.6146	3/16	.7813	3/16	.9479
	.1198		.2865		.4531		.6198		.7865		.9531
1/4	.1250	1/4	.2917	1/4	.4583	1/4	.6250	1/4	.7917	1/4	.9583
	.1302		.2969		.4635		.6302		.7969		.9635
5/16	.1354	5/16	.3021	5/16	.4688	5/16	.6354	5/16	.8021	5/16	.9688
	.1406		.3073		.4740		.6406		.8073		.9760
3/8	.1458	3/8	.3125	3/8	.4792	3/8	.6458	3/8	.8125	3/8	.9762
	.1510		.3177		.4844		.6510		.8177		.9844
7/16	.1563	7/16	.3229	7/16	.4896	7/16	.6563	7/16	.8229	7/16	.9896
	.1615		.3281		.4948		.6615		.8281		.9948

"C. G. S." SYSTEM OF UNITS.

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THE "C. G. S." SYSTEM OF UNITS.*

First Report of the Committee for the Selection and Nomenclature of Dynamical and Electrical Units, the Committee consisting of Sir W. Thomson, F.R.S., Professor G. C. Foster, F.R.S., Professor J. C. Maxwell, F.R.S., Mr. G. J. Stoney, F.R.S.,† Professor Fleeming Jenkin, F.R.S., Dr. Siemens, F.R.S., Mr. F. J. Bramwell, F.R.S., and Professor Everett (Reporter).

WE consider that the most urgent portion of the task intrusted to us is that which concerns the selection and nomenclature of units of force and energy; and under this head we are prepared to offer a definite recommendation.

A more extensive and difficult part of our duty is the selection and nomenclature of electrical and magnetic units. Under this head we are prepared with a definite recommendation as regards selection, but with only an interim recommendation as regards nomenclature.

Up to the present time it has been necessary for every person who wishes to specify a magnitude in what is called "absolute" measure, to mention the three fundamental units of mass, length and time which he has chosen as the basis of his system. This necessity will be obviated if one definite selection of three fundamental units be made once for all and accepted by the general consent of scientific men. We are strongly of opinion that such a selection ought at once to be made, and to be so made that there will be no subsequent necessity for amending it.

We think that, in the selection of each kind of derived unit, all arbitrary multiplications and divisions by powers of

* See Units and Physical Constants, by J. D. Everett; London: 1877, for extended tables of physical constants in the C.G.S. system.

† Mr. Stoney did not concur in the recommendations of this report, and is not responsible for the C.G.S. system.

ten, or other factors, must be rigorously avoided, and the whole system of fundamental units of force, work, electrostatic, and electro-magnetic elements must be fixed at one common level—that level, namely, which is determined by direct derivation from the three fundamental units once for all selected.

The carrying out of this resolution involves the adoption of some units which are excessively large or excessively small in comparison with the magnitudes which occur in practice; but a remedy for this inconvenience is provided by a method of denoting decimal multiples and submultiples, which has already been extensively adopted, and which we desire to recommend for general use.

On the initial question of the particular units of mass, length, and time to be recommended as the basis of the whole system, a protracted discussion has been carried on, the principal point discussed being the claims of the gramme, the *metre*, and the second, as against the gramme, the *centimetre*, and the second,—the former combination having an advantage as regards the simplicity of the name *metre*, while the latter combination has the advantage of making the unit of mass practically identical with the mass of unit-volume of water—in other words, of making the value of the density of water practically equal to unity. We are now all but unanimous in regarding this latter element of simplicity as the more important of the two; and in support of this view we desire to quote the authority of Sir W. Thomson, who has for a long time insisted very strongly upon the necessity of employing units which conform to this condition.

We accordingly recommend the general adoption of the *Centimetre*, the *Gramme*, and the *Second*, as the three fundamental units; and until such time as special names shall be appropriated to the units of electrical and magnetic magnitude hence derived, we recommend that they be distinguished from "absolute" units otherwise derived, by the letters "C.G.S." prefixed, these being the initial letters of the names of the three fundamental units.

Special names, if short and suitable, would, in the opinion

of a majority of us, be better than the provisional designations "C.G.S. unit of . . . ." Several lists of names have already been suggested: and attentive consideration will be given to any further suggestions which we may receive from persons interested in electrical nomenclature.

The "ohm," as represented by the original standard coil, is approximately 10^9 C.G.S. units of resistance; the "volt" is approximately 10^8 C.G.S. units of electromotive force; and the "farad" is approximately $\frac{1}{10^9}$ of the C.G.S. unit of capacity.

For the expression of high decimal multiples and submultiples, we recommend the system introduced by Mr. Stoney, a system which has already been extensively employed for electrical purposes. It consists in denoting the exponent of the power of 10, which serves as a multiplier, by an appended cardinal number, if the exponent be positive, and by a prefixed ordinal number if the exponent be negative.

Thus 10^9 grammes constitutes a *gramme-nine*; $\frac{1}{10^9}$ of a gramme constitutes a *ninth-gramme*; the approximate length of a quadrant of one of the earth's meridians is a *metre-seven*, or a *centimetre-nine*.

For multiplication or division by a million, the prefixes *mega** and *micro* may conveniently be employed, according to the present custom of electricians. Thus the *megohm* is a million ohms, and the *microfarad* is the millionth part of a farad. The prefix *mega* is equivalent to the affix *six*. The prefix *micro* is equivalent to the prefix *sixth*.

The prefixes *kilo*, *hecto*, *deca*, *deci*, *centi*, *milli* can also be employed in their usual senses before all new names of units.

As regards the name to be given to the C.G.S. *unit of force*, we recommend that it be a derivative of the Greek δύναμις. The form *dynamy* appears to be the most satisfactory to etymologists. *Dynam*, is equally intelligible, but

* Before a vowel, either *meg* or *megal*, as euphony may suggest, may be employed instead of *mega*.

awkward in sound to English ears. The shorter form, *dyne*, though not fashioned according to strict rules of etymology, will probably be generally preferred in this country. Bearing in mind that it is desirable to construct a system with a view to its becoming international, we think that the termination of the word should for the present be left an open question. But we would earnestly request that, whichever form of the word be employed, its meaning be strictly limited to the unit of force of the C.G.S. system—that is to say, *the force which, acting upon a gramme of matter for a second, generates a velocity of a centimetre per second.*

The C.G.S. *unit of work* is the work done by *this force working through a centimetre*, and we propose to denote it by some derivative of the Greek ἔργον. The forms *ergon*, *ergal*, and *erg* have been suggested; but the second of these has been used in a different sense by Clausius. In this case also we propose, for the present, to leave the termination unsettled; and we request that the word *ergon*, or *erg*, be strictly limited to the C.G.S. unit of work, or what is, for purposes of measurement, equivalent to this, the C.G.S. *unit of energy*, energy being measured by the amount of work which it represents.

The C.G.S. *unit of power* is the power of doing work at the rate of *one erg per second;* and the power of an engine, under given conditions of working, can be specified in *ergs per second.*

For rough comparison with the vulgar (and variable) units based on terrestrial gravitation, the following statement will be useful:

The *weight* of a *gramme*, at any part of the earth's surface, is about 980 *dynes*, or rather less than a *kilodyne.*

The *weight* of a *kilogramme* is rather less than a *megadyne*, being about 980,000 *dynes.*

Conversely, the *dyne* is about 1.02 times the *weight* of a *milligramme* at any part of the earth's surface; and the *megadyne* is about 1.02 times the *weight* of a *kilogramme.*

The *kilogrammetre* is rather less than the *ergon-eight*, being about 98 million *ergs.*

The *gramme-centimetre* is rather less than the *kilerg*, being about 980 *ergs*.

For exact comparison, the value of g (the acceleration o a body falling in vacuo) at the station considered must of course be known. In the above comparisons it is taken as 980 C.G.S. units of acceleration.

One *horse-power* is about three-quarters of an *erg-ten* per second. More nearly, it is 7.46 *erg-nines* per second, and one *force-de-cheval* is 7.36 *erg-nines* per second.

The mechanical equivalent of one *gramme-degree* (Centigrade) of heat is 41.6 megalergs, or 41,600,000 *ergs*.

TABLES FOR REDUCING OTHER MEASURES TO C.G.S. MEASURES.*

The abbreviation *cm.* is used for *centimetre* or *centimetres.*
gr. " *gramme* or *grammes.*
sec. " *second* or *seconds.*
sq. " *square.*
cub. " *cubic.*

TABLE A.

Length.

1 inch	=	2.5400	cm.
1 foot	=	30.4797	"
1 yard	=	91.4332	"
1 mile	=	160933	"
1 nautical mile	=	185230	"

More exactly, according to Captain Clarke's comparisons of standards of length (printed in 1866), the metre is equal to 1.09362311 yard, or to 39.370432 inches, the standard metre being taken as correct at 0°C., and the standard yard as correct at 16⅔° C. Hence the inch is 2.5399772 centimetres.

TABLE B.

Area.

1 square inch	=	6.4516	sq. cm.
1 square foot	=	929 01	"
1 square yard	=	8361.13	"
1 square mile	=	2.59×10^{10}	"

TABLE C.

Volume.

1 cubic inch	=	16.387	cub. cm.
1 cubic foot	=	28316	"
1 cubic yard	=	764535	"
1 pint	=	567.63	"
1 gallon	=	4541	"

* J. D. Everett, Abstract.

TABLE D.

Mass.

1 grain	=	.064790	gm.
1 ounce avoirdupois	=	28.3495	"
1 pound "	=	453.59	"
1 ton	=	1.01605×10^6	"

More exactly, according to the comparisons made by Professor W. H. Miller in 1844 of the "kilogramme des Archives," the standard of French weights, with two English pounds of platinum, and additional weights, also of platinum, the kilogramme is 15432.34874 grains, of which the new standard pound contains 7000. Hence the kilogramme is 2.2046212 pounds, and the pound is 453.59265 grammes.

TABLE E.

Velocity.

1 foot per second	= 34.4797	cm. per sec.
1 statute mile per hour	= 44.704	"
1 nautical mile per hour	= 51.453	"
1 kilometre per hour	= 27.777	"

TABLE F.

Density.

Pure water at temperature of maximum density	1.000013	gm. per cub. cm.
1 pound per cubic foot	= .016019	

TABLE G.

Force (assuming $g = 981$).

Weight of 1 grain	= 63.57		dynes, nearly.
" of 1 ounce avoirdupois	= 2.78	$\times 10^4$	"
" of 1 pound avoirdupois	= 4.45	$\times 10_5$	"
" of 1 cwt	= 4.98	$\times 10^7$	"
" of 1 ton	= 9.97	$\times 10^8$	"
" of 1 gramme	= 981		"
" of 1 kilogramme	= 9.81	$\times 10^5$	"
" of 1 tonne	= 9.81	$\times 10^8$	"

TABLE H.

Work (assuming $g = 981$).

1 foot-pound	= 1.356	$\times 10^7$	ergs, nearly.
1 foot-grain	= 1.937	$\times 10^3$	"
1 foot-ton	= 3.04	$\times 10^{10}$	"
1 milligram-millimetre	= 9.81	$\times 10^2$	"
1 gramme-centimetre	= 9.81	$\times 10^2$	"
1 kilogrammetre	= 9.81	$\times 10^7$	"
1 tonne-metre	= 9.81	$\times 10^{10}$	"
Work in a second by one theoretical "horse"	= 7.46	10^9	"

TABLE I.

Pressure (assuming $g=981$).

1 pound per square foot....	= 479	dynes per sq. cm.,	nearly.
1 pound per square inch....	= 6.9 × 10^4	"	"
1 kilogramme per square metre.....	= 98.1	"	"
1 kilogramme per square decimetre.....	= 9.81 × 10^3	"	"
1 kilogramme per square centimetre.....	= 9.81 × 10^5	"	"
1 kilogramme per square millimetre.....	= 9.81 × 10^7	"	"
Pressure of 760 millimetres of mercury at 0° C.....	= 10.14 × 10^6	"	"

TABLE J.

Heat.

1 gramme-degree Centigrade	= 4.2 × 10^7 ergs = 42 million ergs.
1 pound-degree "	= 1.91 × 10^{10} ergs.
1 " Fahr.....	= 1.06 × 10^{10} ergs.

Thermal Conductivity.

Thermal Conductivity is measured in "C.G.S." units by the number of C.G.S. units of heat flowing per second along a bar of one square centimetre section with a difference of temperature of one degree on the opposite sides. It is the value of k in

$$E = k A \frac{T_2 - T_1}{x} t$$

in which E is the quantity of heat flowing, in the time t, through a plate of the thickness x and area A, the temperature on the opposite forces being T_1 and T_2 and constant. The values of k are

TABLE K.

THERMAL CONDUCTIVITY.—VALUES OF k PECLET.

	Density.	Conductivity.
Copper.....	.....	.178
Iron.....	.....	.081
Zinc.....	.....	.078
Lead.....	.....	.039
Carbon from gas-retorts.....	1.61	.0138
Marble, fine-grained grey.....	2.68	.0097
" sugar-white, coarse-grained.....	2.77	.0077
Limestone, fine-grained.....	2.34	.0058
" "	2.27	.0047
" "	2.17	.0035

THERMAL CONDUCTIVITY.—*Continued.*

	Density.	Conductivity.
Lias building stone, coarse-grained	2.22	.0037
" "	2.24	.0035
Plaster of Paris, ordinary, made up	.....	.00092
" very fine, "	1.25	.00144
" for casts, very fine } " made up }	1.25	.00122
Alum paste, (marble-cement) "	1.73	.00175
Terra-cotta	1.98	.00192
"	1.85	.00142
Fir, across fibres	.48	.00026
" along fibres	.48	.00047
Walnut, across fibres	.....	.00029
" along fibres	.....	.00048
Oak, across fibres	.....	.00059
Cork	.22	.00029
Cautchouc	.....	.00041
Gutta percha	.....	.00048
Starch paste	1.017	.00118
Glass	2.44	.0021
"	2.55	.0024
Sand, quartz	1.47	.00075
Brick, pounded, coarse-grained	1.0	.00039
" passed through silk sieve	1.76	.00046
Fine brickdust, obtained by decantation	1.55	.00039
Chalk, powdered, slightly damp	.92	.00030
" washed and dried	.85	.00024
" washed, dried and compressed	1.02	.00029
Potato-starch	.71	.00027
Wood-ashes	.45	.00018
Mahogany sawdust	.31	.00018
Wood charcoal, ordinary, powdered	.49	.00022
Bakers' breeze, in powder, passed thro' silk sieve	.25	.00919
Ordinary wood charcoal, in powder, passed through silk sieve	.41	.000225
Coke, powdered	.77	.00044
Iron filings	2.05	.00044
Binoxide of manganese	1.46	.00045
Cotton-wool, of all densities	....	.000111
Cotton swansdown (molleton de coton) of all densities	....	.000111
Calico, new, of all densities	....	.000139
Wool, carded, of all densities	....	.000122
Woollen swansdown (molleton de laine), of all densities	....	.000067
Eider-down	....	.000108
Hempen cloth, new	.54	.000144
" old	.58	.000119
Writing-paper, white	.85	.000119
Grey paper, unsized	.48	.000094

Emission of Surface Conduction.

M'Farlane has published (Proc. Roy. Soc. 1872, p. 93) the result of experiments on the loss of heat from blackened and

polished copper in air at atmospheric pressure. They need no reduction, the units employed being the centimetre, gramme, and second. The general result is expressed by the formulæ

$$x = .000238 + 3.06 \times 10^{-6} t - 2.6 \times 10^{-8} t^2$$

for a blackened surface, and

$$x = .000168 + 1.98 \times 10^{-6} t - 1.7 \times 10^{-8} t^2$$

for polished copper, x denoting the quantity of heat lost per second per square centimetre of surface of the copper, per degree of difference between its temperature and that of the walls of the enclosure. These latter were blackened internally, and were kept at a nearly constant temperature of 14° C. The air within the enclosure was kept moist by a saucer of water. The greatest difference of temperature employed in the experiments (in other words, the highest value of t) was 50° or 60° C.

The following Table contains the value of x calculated from the above formulæ, for every fifth degree, within the limits of the experiments.

TABLE L.

Difference of Temperature.	Value of x.		Ratio.
	Polished Surface.	Blackened Surface.	
5°	.000178	.000252	.707
10	.000186	.000266	.699
15	.000193	.000279	.692
20	.000201	.000289	.695
25	.000207	.000298	.694
30	.000212	.000306	.693
35	.000217	.000313	.693
40	.000220	.000319	.693
45	.000223	.000323	.690
50	.000225	.000326	.690
55	.000226	.000328	.690
60	.000226	.000328	.690

ELECTRICAL RESISTANCE.

The electrical resistance of a wire (or more generally of a prism or cylinder) of given material varies directly as its length, and inversely as its cross section. It is therefore equal to

$$R\,\frac{\text{length}}{\text{section}},$$

where R is a coefficient depending only on the material. R is called the *specific resistance* of the material. Its reciprocal $\frac{1}{R}$ is called the *specific conductivity* of the material.

The values of R, as deduced from Matthiessen's experiments, are thus given:

TABLE M.

ELECTRICAL RESISTANCE.—VALUES OF R.

	Specific resistance.		Percentage of variation for a degree at 20° C.
Silver, annealed	1521	.....	.377
" hard drawn	1652		
Copper, annealed	1615	.....	.388
" hard-drawn	1652		
Gold, annealed	2081	.....	.365
" hard-drawn	2118		
Aluminium, annealed	2946		
Zinc, pressed	5690	.....	.365
Platinum, annealed	9158		
Iron, annealed	9827		
Nickel, annealed	12600		
Tin, pressed	13360	.....	.365
Lead, pressed	19850	.....	.387
Antimony, pressed	35900	.....	.389
Bismuth, pressed	132650	.....	.354
Mercury, liquid	96190	.....	.072
Alloy, 2 parts platinum, 1 part silver, by weight, hard or annealed	2466	.....	.031
German silver, hard or annealed	21170	.....	.044
Alloy, 2 parts gold, 1 silver by weight, hard or annealed	10990	.....	.065

Resistances of Conductors of Telegraphic Cables per nautical mile, at 24° C., in electro-magnetic measure.

Red Sea	7.94×10^9
Malta-Alexandria, mean	3.49 "
Persian Gulf, mean	6.284 "
Second Atlantic, mean	4.272 "

YOUNG'S MODULUS OF ELASTICITY.

As has been already stated, the quotient $\frac{\text{stress}}{\text{strain}}$ is called "Young's Modulus of Elasticity," or briefly "Young's Modulus."

When the stress is a shearing stress, and the strain is the shear produced, the planes of the stress being the same as the planes of the shear, the quotient $\frac{\text{stress}}{\text{strain}}$ is called the "simple rigidity," for these planes.

When the stress consists in hydrostatic pressure, and the strain is the compression produced, the quotient $\frac{\text{stress}}{\text{strain}}$ is called the "elasticity of volume," or the "coefficient of volume-elasticity," just as in the case of a liquid.

The values in the following table are reduced from those given in Prof. Everett's papers to the Royal Society (see Phil. Trans. 1867, p. 369):

TABLE N.

YOUNG'S MODULUS.

	YOUNG'S MODULUS.	SIMPLE RIGIDITY.	ELASTICITY OF VOLUME.	DENSITY.
Glass, flint.....	6.03 × 10^{11}	2.40 × 10^{11}	4.15 × 10^{11}	2.942
Another specimen...	5.74 "	2.35 "	3.47 "	2.935
Brass, drawn.....	1.075 × 10^{12}	3.66 "	..	8.471
Steel.....	2.139 "	8.19 "	1.841 × 10^{12}	7.849
Iron, wrought.....	1.963 "	7.69 "	1.456 "	7.677
" cast.....	1.349 "	5.32 "	9.64 × 10^{11}	7.235
Copper.....	1.234 "	4.47 "	1.684 × 10^{1}	8.843

The following are reduced from Sir W. Thomson's results (Proc. Roy. Soc., May 1865):

	Simple Rigidity.			
Brass, three specimens.....	4.03	3.48	3.44	× 10^{11}
Copper, two specimens.....	4.40	4.40		

Other specimens of copper in abnormal states gave results ranging from 3.86 × 10^{11} to 4.64 × 10^{11}.

The following are reduced from Wertheim's results (Ann. de Chim. ser. 3. tom. xxiii.):

DIFFERENT SPECIMENS OF GLASS (CRYSTAL).

Young's modulus	3.41 to 4.34,	mean	3.96	× 10^{11}
Simple rigidity	1.26 to 1.66,	"	1.48	
Volume-elasticity	3.50 to 4.39,	"	3.89	

DIFFERENT SPECIMENS OF BRASS

Young's modulus	9.48 to 10.44,	mean	9.86	× 10^{11}
Simple rigidity	3.53 to 3.90,	"	3.67	
Volume-elasticity	10.02 to 10.85,	"	10.43	

Savart's experiments on the torsion of brass wire (Ann. de Chim. 1829) lead to the value 3.61×10^{11} for simple rigidity.

Kupffer's values of Young's modulus, for nine different specimens of brass, range from 7.96×10^{11} to 11.4×10^{11}, the value generally increasing with the density.

For a specimen, of density 8.4465, the value was 10.58×10^{11}.

For a specimen, of density 8.4930, the value was 11.2×10^{11}.

The values of Young's modulus found by the same experimenter for steel, range from 20.2×10^{11} to 21.4×10^{11}.

The following are reduced from Rankine's "Rules and Tables," pp. 195 and 196, the mean value being adopted where different values are given:

TABLE O.

YOUNG'S MODULUS.

	TENACITY.	YOUNG'S MODULUS.
Steel bars	7.93×10^9	2.45×10^{12}
Iron wire	5.86 "	1.745 "
Copper wire	4.14 "	1.172 "
Brass wire	3.38 "	9.81×10^{11}
Lead, sheet	2.28×10^8	5.0×10^{10}
Tin, cast	3.17 "	.....
Zinc	5.17 "	.....
Ash	1.172×10^9	1.10×10^{11}
Spruce	8.55×10^8	1.10 "
Oak	1.026×10^9	1.02 "
Glass	6.48×10^8	5.52×10^{11}
Brick and cement	2.0×10^7	.....

The proof load of a substance may be defined as the greatest longitudinal stress that it can bear without permanent distortion. The quotient of the proof load by Young's modulus will therefore be the greatest longitudinal extension that the substance can safely bear.

FOUR FIGURE LOGARITHMS.

FOUR-FIGURE LOGARITHMS.*

NO.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3866	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	6	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	7	9	10

* Extracted from *British Handbook for Field Service.*

FOUR-FIGURE LOGARITHMS.—(*Continued.*)

NO.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7338	7396	1	2	2	3	4	5	6	6	7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	3	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5

FOUR-FIGURE LOGARITHMS.—(*Continued.*)

NO.	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	4	4

INSTRUCTIONS.

To find the logarithm of a given number by the tables.

(*a.*) When the number consists of less than three figures, look in the column marked No. for the number, and immediately opposite to it will be found the logarithm.

Example.

Log. 5 = 0.6990, log. 50 = 1.6990.

(*b.*) When the number consists of more than three figures, look for the first two figures in the column marked No., and along the top row for the third ; the number found at the intersection of the two rows will be the logarithm required.

Example.

Log. 502 = 2.7007, log. 7.21 = 0.8579.

(*c.*) If there be a fourth figure, look for the number corresponding to it among the small columns on the right of the page, and add it to the logarithm corresponding to the first three figures.

Example.

Find logarithm of 1416.

log. 1410 = 3.1492
number corresponds to 6 = 18

log. 1416 = 3.1510

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